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Ulrich Witt

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On the proper interpretation of 'evolution' in economics and its implications for production theory

Ulrich Witt

Abstract How relevant is the notion of evolution for economics? In view of the paradigmatic influence of Darwinian thought, several recently advocated interpretations are discussed first which rely on Darwinian concepts. As an alternative, a notion of evolution is suggested that is based on a few, abstract, common principles which all domain-specific evolutionary processes share, including those in the economy. A different, ontological question is whether and, if so, how the various domain-specific evolutionary processes are connected. As an answer, an evolutionary continuity hypothesis is postulated and its concrete economic implications are discussed exemplarily for the theory of production.

Keywords: evolutionary economics, novelty, selection metaphor, sociobiology, Universal Darwinism, production theory
JEL code: B41, B52, D20, O33

1 INTRODUCTION

The historical record of the economic transformations that have taken place over only the past few decades is dramatic. Few products and services have remained unaltered. Hundreds of thousands of them have been newly created. Rising real income has made all of them affordable for mass consumption. Production techniques and working lives have been deeply transformed. It may be doubted that the equilibrium-cum-optimization heuristic of modern economics – which focuses on states rather than processes – is helpful in conceptualizing this incessant historical transformation of the economy. An 'evolutionary' approach has therefore been proposed as an alternative. However, it is not clear what precisely is implied by the notion of evolution in an economic context and, hence, what progress can be made by adopting an evolutionary approach. 'Evolution' is usually associated today with the billion years old process in which the forms of life on earth emerged – the process that has become intelligible on the basis of Darwin's (1859) theory. Correspondingly, Darwinian principles and their more recent refinements have come to be *the* model of an evolutionary

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theory and pre-Darwinian evolutionary thought in social philosophy, law, and the humanities (cf. Hayek 1967) have been forgotten.

Indeed, the intellectual dominance of the Darwinian approach to evolution also has not failed to influence the modern attempts to conceive of an evolutionary approach to economics. However, these attempts differ significantly with respect to the extent to which they assume an ontological basis in common with the Darwinian theory and, thus, subscribe to the Darwinian world view now prevailing in the sciences. Some of the contributions to evolutionary economics, starting with Veblen (1898), endorse a common ontology. Other contributions, like that of Nelson and Winter (1982), borrow Darwinian concepts for analogous constructions or metaphorical use at a heuristic level and leave open whether there are ontological commonalities with Darwinism. (Some contributions explicitly deny this.) The differing views correspond with different interpretations of the very notion of evolution. In this paper therefore, the pros and cons of the different interpretations will be discussed. An attempt will be made to identify an interpretation which can lead to a fruitful theorizing about the record of the economic transformations. Since human production activities have occurred at all times and in all cultures, the particular aspect for which this will be demonstrated exemplarily are the historical changes in human production together with their implications for the economic theory of production.

The paper proceeds as follows. In view of the paradigmatic influence of Darwinian thought, Section 2 briefly reviews the different positions that have been taken more recently with respect to the role Darwinian concepts could, or should, play in economics. Section 3 extends the discussion to the notion of evolution. Given that the notion is used in various domains with quite different domain-specific connotations, an interpretation will be proposed which refers to a few, abstract, common principles which all domain-specific evolutionary processes share. A different, namely ontological, question is whether or not there are (inter-) dependencies between domain-specific evolutionary processes. To answer that question, the hypothesis of an ontological continuity between evolution in nature and in the economy will be introduced. Section 4 explains how the continuity hypothesis can be made fruitful for an analysis of evolutionary economic change with an exemplary reconstruction of the conditions from which human production started to evolve. The reconstruction requires an approach to production that is more 'naturalistic' than the one usually taken in economics where all efforts went into developing ever more abstract versions of production theory. Some of the implications of both the reconstruction of, and the concomitant 'naturalistic' approach to, changing human production activities for the theory of the factors of production and economic growth are then discussed in Section 5. Section 6 offers the conclusions.

2 DIFFERENT VIEWS OF THE ROLE OF DARWINIAN CONCEPTS

There are many ways of referring to Darwinian thought – with or without sharing its ontological assumptions – in the attempt to add substance to the notion of evolution in economics. Four heuristic strategies seem particularly worth mentioning here. A *first*, and most radical, strategy is the attempt to apply the neo-Darwinian theory of natural selection directly to human economic behavior.[1] The ontological basis of this interpretation is essentially the same as that of evolutionary biology in general and sociobiology in particular. The argument may be sketched as follows. Economic phenomena result from human behavior. Humans are themselves a product of natural selection. Accordingly, observable economic behavior should be explicable in terms of its contribution to genetic fitness.

The problem with such an explanation is, of course, that, strictly speaking, it applies only to genetically determined forms of behavior. Moreover, it requires assuming that selection pressure on humans is still tight enough to ensure that deviations from the best fit behavior (in terms of reproductive success) tend to be wiped out. While for the early, primitive, human economy this may be a reasonable working hypothesis, the conditions in the much more productive modern economy seem to be different. Indeed, in modern economies, the most significant part of the adaptations in economic behavior occur within one generation, i.e. at a pace much more rapid than that of inter-generational, genetic adaptation. The intra-generational adaptations result from learning and insight which can be associated with cultural, rather than natural, evolution and, as such, are inaccessible to neo-Darwinian theory.[2]

A *second* strategy for pursuing Darwinian ideas – the one currently most popular in evolutionary economics – not only rejects biological reductionism, but also denies the existence of a common ontological basis with evolutionary biology. Instead, an attempt is made to use Darwinian concepts in a purely heuristic fashion. This involves either aiming at constructing analogies between the principles of evolutionary economics and those of evolutionary biology, or at deriving metaphorical inspiration (cf. Hodgson 1999, Part II and Vromen 2001 for a discussion). However, because of obvious lack of anything in the economic domain comparable to the genetic reproduction mechanism, a true analogy cannot be expected to hold. Darwinian concepts, most notably the principle of natural selection, are therefore usually only borrowed as metaphors to conceptualize evolutionary change in the economic domain. Such a heuristic use of Darwinian concepts of course runs the risk of guiding theorizing away from the actual conditions prevailing in the economic domain. (A misleading heuristic resulted, e.g., in the case of the prominent attempt at constructing an analogy between classical mechanics and neoclassical economics, cf. Mirowski 1989.)

A major difference which a heuristic use of the selection principle tends to ignore lies in the fact that, whatever is supposed to be the unit of selection in the economic domains, it cannot be expected to show as much inertia as its biological analogue. This seems to be the problem, for example, in the use Nelson and Winter (1982), the leading proponents of evolutionary economics, make of the natural selection metaphor.[3] In order for natural selection to exert a systematic, shaping influence, some relative inertia are required to exist in the population subject to selection. In a turbulent environment characterized by many things changing simultaneously, natural selection is not capable of producing any systematic change. However, it is precisely such a turbulent environment that characterizes modern economies, not least because humans have sufficient intelligence and incentives to anticipate and avoid selection effects.[4] The selection metaphor may therefore divert attention from what seems to be crucially important for economic evolution – the role played by cognition, learning, and growing knowledge.[5] Adaptations which result from cognitive processes like hypothesis formation and learning from insight follow their own regularities which in both their dynamics and their outcome are unlikely to equal genetic selection processes.

A *third* strategy for pursuing Darwinian ideas, particularly the concept of natural selection, outside biology in general, and in evolutionary economics in particular, is that of 'Universal Darwinism' (Dawkins 1983). It has recently been clearly articulated by Hodgson (2002). Like the previous strategy focusing on metaphorical uses, this interpretation also suggests making use of Darwinian concepts but, unlike the previous strategy, in a substantial rather than in a heuristic form. As the label of Universal Darwinism indicates, the intention is to apply Darwinian concepts to all forms and levels of life. In contrast to the previous strategy, this presupposes that there is only one and the same ontological basis for all evolutionary phenomena. However, it is not this ontological assertion (which is also shared by the fourth position to be discussed in a minute) that appears as a problem. The problem rather is the general validity of the principles suggested by Darwin for explaining evolution in nature which is claimed for all forms of evolution.

As Hodgson (2002) points out, this third strategy of propagating Darwinian ideas as general purpose tools for coming to grips with evolutionary phenomena has a tradition in the post-Darwinian natural philosophy. A particularly popular version of it has been suggested by Campbell (1965). He argued that any theory of evolution is based on the abstract principles of variation, selection, and retention (or replication). Yet, as is easy to see, these principles are an abstract reduction of the neo-Darwinian theory in evolutionary biology.[6] Their invocation outside biology therefore amounts to nothing more than an attempt to construct an abstract analogy to the domain-specific model of evolutionary biology. As has just been outlined, such analogies – which are always already a result of abstraction – do not really work. Therefore, this strategy is likely to face interpretative problems like those just discussed in the context of the second strategy. Again, this is particularly obvious for the crucial test criterion for Darwin's theory of evolution: the absence of a systematic feedback between selection and variation. Such a feedback is characteristic, e.g., for economic evolution where people invent their way out when threatened by "selection forces". In the presence of a systematic feedback, the distinction between variation and selection, which is a fundamental premise of the neo-Darwinian theory, is no longer valid – a result that does not just live up to the expectations of Universal Darwinism.

A *fourth* strategy for making use of Darwinian thought for understanding economic evolution will be advocated in more detail in the remainder of this paper. As mentioned above, it also presumes one and the same ontological basis for all evolutionary phenomena, but tries to avoid over-expanding the domain of Darwinian concepts. The basis for doing so involves a somewhat more complex argument, labeled the 'continuity hypothesis', which connects evolutionary biology to, e.g., evolutionary economics (cf. Witt 1987: Ch. III; 1999, 2003). The fact that humans and their 'hardwired' endowment are a result of natural selection also figures prominently in this interpretation. (To recall, this is at the core of the first, above mentioned, strategy that tries to apply Darwinian theory directly to economic behavior). However, these genetic endowments are considered only as setting the stage for yet other forms of evolution which have emerged under the influence of the unfolding human culture. The latter forms follow their own regularities and interact both among themselves and with natural evolution in an increasingly richer and more complex way. Thus, an ontological continuity is assumed in which new forms of change have been generated within the freedom left by the constraints of Darwinian theory – and, hence, without invalidating that theory. To discuss and compare the different forms of evolution it is necessary, first, to develop some conceptual means by which the domain specific connotations of evolution can be transcended. This will be done in the next section to prepare the ground for the subsequent reflections on how evolution 'continues' within the economic domain.

3 DIFFERENT FORMS OF EVOLUTION AND THE CONTINUITY HYPOTHESIS

The notion of evolution was neither invented by Darwin, nor does evolution occur in nature alone. Culture, society, and the economy all evolve too. In fact, before Darwin, these were center stage in the thought of philosophers, lawyers, and social reformers who conceived the very notion of evolution as something emerging and systematically unfolding.[7] Defined in this broad sense, evolution can indeed be diagnosed in different domains which are today covered by different disciplines like, say, biology, linguistics, or economics. Does this mean that the evolution that occurs in the different domains takes on domain-specific forms? If so, do these different forms have some generic features in common, features that should be observable wherever evolution is said to take place – be it, say, in nature, in human languages, or in the human economy? It is presumably not controversial to answer both questions in the affirmative. Dissent is about what the generic features of evolution are.

As mentioned in the previous section, Universal Darwinism considers variation, selection, and retention/replication as generic features of evolution. However, these three principles and the relationships between them depend on a heuristic inspired by neo-Darwinian evolutionary biology and, as such, are still domain-specific. As argued elsewhere (Witt 1987: Ch. 1, 1993, 2003: Ch. 1), a way of arriving at generic features of evolution, and an alternative to constructing analogies, is the attempt to transcend the domain-specific conditions by generalization. Thus, by generalization it may be inferred that evolution is a dynamic governed by some regularities. Yet, even though this is a necessary condition, it is not sufficient for characterizing evolutionary processes. There are many dynamic processes displaying regularities which are usually not considered evolutionary – e.g. the stochastic process describing the motion of a particle suspended in a liquid known as Brownian motion. The necessary and sufficient condition is, it may therefore be claimed, that evolutionary dynamic processes have the capacity of expanding their state space through the generation of not previously existing states.

This means that the generation of novelty is considered generic here to all cases of evolution or, to put it differently, that evolution is the self-transformation over time of a system under consideration. The term 'transformation' means a process of change governed by regularities. The prefix in '*self*-transformation' points to the endogenous sources and causes of novelty.[8] Self-transformation can be split into two logically, and usually also ontologically, distinct processes: the emergence and the dissemination of novelty. These two processes, it will be submitted, are two characteristic, domain-transcending features of evolution. As expected, in the different disciplinary domains the two features appear in quite different forms. In biology, there is random mutation and genetic recombination on the one hand and selective replication in the gene pool of a population on the other. In linguistics, the invention of new idioms marks the emergence part and their popularization the dissemination part. In the economic domain, given the discipline's focus on human action, novelty is usually identified with new possibilities of action which, once taken, are called innovations. Any attempt to innovate is, of course, likely to be accompanied by learning which may trigger further novelty.[9]

At this point we can now return to the fourth strategy above mentioned for relating Darwinian thought to economic evolution. This strategy is based on the 'continuity hypothesis' and can perhaps best be epitomized as follows. In the autumn of the year 1835, on his five years trip around the world, Darwin arrived at the Galapagos Islands in the Pacific Ocean, some seven hundred miles west of what is now Ecuador on board of her Majesty's sailing ship Beagle. During his trip Darwin, like many other naturalists of his time, recorded nature's impressive richness of still unknown species. The isolated archipelagos of the Galapagos Islands were basically untouched by human settlement at those times and offered a rich and stunning variety of unique species. Among them was a variety of finches from the very different islands of the archipelagos. Darwin concluded that these populations of finches represented own species which, however, must have had one common ancestor that, most likely, had immigrated to the Galapagos Islands much earlier. This finding, which was later confirmed, had a crucial impact on how Darwin conceived a theory of speciation in his general evolutionary scheme (Mayr 1991: Ch. 1).

Scholars interested in recording the products of evolution who visited the Galapagos Islands today would obtain different findings. Instead of observing some new species they would find cottages, roads, landing fields, radar stations, and many other human artefacts not present in Darwin's time less than two hundred years ago. There is no indication of any genetic program to which these artefacts would have given expression, but some kind of program does seem to have been involved in their being made at the different points in time. In the light of this much different finding, scholars visiting the Galapagos Islands today would probably feel inclined to ask themselves what form of evolution could be held responsible for these kinds of changes and how it relates to evolution in nature. It is precisely this question that the continuity hypothesis addresses. As suggested by the generic characterization of evolution as processes of the emergence and dissemination of novelty, there are several different, domain-specific realizations of these processes. The differences between them not withstanding, it may be conjectured that their ontological basis is somehow related.

Indeed, it is this conjecture which allows the Darwinian world view to be expended to accommodate for the emergence of culture and its own forms of evolution. While natural evolution – 'the origin of the species by means of natural selection' as Darwin (1859) put it – is only one form in which evolution occurs in reality, it is the form that, in historical time, anteceded the other forms of evolution considered here. It has therefore shaped the ground, and still defines the constraints, for man-made, or cultural, evolution. In this sense there is, thus, also a historical ontological continuity, the fact not withstanding that the mechanisms and regularities of cultural evolution differ from those of natural evolution. The historical process of economic evolution can be conceived as emerging from, and being embedded in, the constraints shaped by evolution in nature. Darwinian theory is directly relevant to understanding the origin of economic evolution in human phylogeny and the fact that it has a lasting influence through innate elements of human behavior. Yet, in the further course of economic evolution, human behavior and, correspondingly, economic activities and their collective outcomes underwent a metamorphosis into the distinct, idiosyncratic forms observable in present-day economies. To explain the emergence of the latter, Darwinian theory is not sufficient. The many facets of cultural evolution require explanatory theories of their own.

The continuity just specified has two concrete implications for those explanatory theories. First, it suggests that innate dispositions and adaptation mechanisms in humans, which have been shaped by natural selection, determine the basic behavioral repertoire upon which other forms of evolution rest. In the early phases of human culture, natural and man-made evolution (including economic evolution) presumably interacted mutually or 'co-evolved'.[10] However, the synergisms between the natural and cultural results of natural selection eventually allowed forms of human behavior to emerge which gave a strong relative reproductive success compared to other species (Corning 2003). As a consequence, selection pressure was significantly reduced. Therefore, it can be argued that the basic genetic endowment of modern man is very similar to the one that was established by the time natural selection stopped being a shaping force. The more selection pressure faded during human phylogeny, the more behavioral variety that did not necessarily possess adaptive value in terms of genetic fitness could increase. This is now the room in which culture, institutions, technology, and economic activities evolve according to their own regularities. (These regularities still include, of course, the constraints on behavior resulting from the innate individual dispositions and adaptation mechanisms which are still in place.)

Second, in the development just characterized, the connection between natural and man-made evolution obviously resolves into an increasingly indirect one. Nonetheless, evolution in nature continues to represent a constraint for what can evolve in culture and the economy, albeit a dynamic one (Faber and Proops 1998). It has in recent times become looser as a result of human inventiveness. Indeed, the significant feature encountered when exploring the shifting constraints of an enlarging human niche and the corresponding decreasing selection pressure on mankind is human intelligence. As Veblen (1898) already had it, intention and learning from insight matter in as much as they permit cumulative problem solving and accumulation of knowledge (not so much, in contrast, in allowing economizing on scarce resources). Where natural evolution was once driven by newly emerging genetic variants and their selective diffusion processes, cultural and economic evolution is now driven by the dynamics of individual and collective human learning processes. The fundamentally different mechanisms by which evolution is brought about in the two cases result, not least, in a dramatically different pace of evolutionary change.

The question that remains now is: what do these conceptual reflections imply for economic theory proper? Do the identified generic features of evolution, the recognized domain-specific forms in which they materialize, and the suggested continuity hypothesis lead to reinterpretations in economic theory? If so, in what way? It may be useful to give at least an exemplary outline of how the consideration can indeed lead to a reframing of old economic problems and the identification of new ones. The ultimate aim is, of course, to derive explanatory hypotheses which can help in understanding the historical process of economic change. The case to be chosen for outlining these implications is human economic production and its growth over historical time.

4 RECONSTRUCTING THE POINT OF DEPARTURE IN HUMAN PRODUCTION

The current state of nature shaped by the evolutionary forces of natural selection has been said to represent a constraint on human productive activity. For most of human history it was experienced as the burden of 'nature's parsimony', as Ricardo once put it. And at all times, humans have tried to use their creativity and problem-solving capacity to work on that constraint in order to alleviate the burden. The long term evolution of human production reflects this constant endeavor.[11] How can this process be characterized in more detail? Are there any regularities which allow explanatory hypotheses to be formulated? The discussion on the continuity hypothesis suggests a basic conjecture: early in human phylogeny productive activities must have been mainly the result of genetically shaped, instinctive behavior until culturally shaped practices emerged which started to deviate from the innate programs. If this conjecture is true, an attempt can be made to reconstruct the point of departure of cultural and economic evolution in production practices by looking into the conditions under which early humans had to undertake their productive efforts.

An extraterrestrial observer visiting this planet some forty thousand years ago would presumably have had little reason to distinguish in principle between the productive activities of early man and those of other living beings like, e.g., higher mammals. If so, then it should be possible to reconstruct – in line with the continuity hypothesis – the conditions of early human production from what "production" means in non-human nature still today.[12] Prerequisite for such a study is obviously a more concrete, 'naturalistic' description of production than it is usual in economics (with the exception of engineering production approaches).[13] To start with, production can be characterized generically in physical terms as the generation or effecting of processes or objects (the 'output') by a controlled application of substances and/or forces (the 'input') according to the natural laws and the systemic relationships prevailing in a domain. Seen this way, production is ubiquitous in living nature, though the term 'production' is hardly ever used in that context.

Take, for example, the metabolism of living organisms. In this 'production process', the complex output is the maintained life function of the organisms, including the maintenance of the organized, living structure of which they are made up. The inputs are essentially the organized living structure itself, energy, minerals, water, and oxygen. The organized living structure, in turn, is generated and maintained by 'production processes' called anabolism (building up of cells, tissues, organs) and catabolism (breaking down tissue and splitting of larger protoplasmic molecules into smaller ones). All these natural production processes are governed by complex cascades of protein interactions which basically follow procedures which are genetically coded in nucleic acids.[14]

It is a built-in feature of these natural production processes that the genetic information is automatically reproduced over and again, subject to the shaping forces of natural selection. In a sense, thus, the 'technology' on which production in living nature operates hinges on the 'knowledge' that has evolved in the form of genetic information along with the biochemical reaction of its 'expressing' over millions of years in the gene pool of the living organisms. Further 'production technologies' have emerged in the animal kingdom, a comparatively late fruit of evolution in nature, namely those including, and based on, the anatomic and physical prerequisites for motility. Chemical energy has to be transformed into kinetic energy which, in turn, has to be transformed into physical work (force × distance), presupposing an anatomic apparatus capable of carrying out the mechanical transmissions. The "output" that becomes feasible in this way are more complex forms of behavior that enable the animal to escape from, and/or combat with, predators, to conquer and defend a habitat, to engage in territorial feeding and mating strategies, and many other forms of social behavior. Carnivores are enabled, moreover, to engage in hunting – often in socially organized ways.

A special form of genetically evolved 'production processes' in nature – particularly relevant to man as will turn out below – are the symbiotic ones. In these processes, 'output' produced by the exemplars of one species are not only "inputs" for the exemplars of another species, but the behavior of the species is also coordinated on the basis of either mutualism (a situation in which both parties involved benefit from each other), commensalism (in which cases the benefits are one-sided, but not detrimental to the non-profiting party) or parasitism (with one-sided benefits and damage caused to the exploited party).

The productive activities in the animal kingdom are largely an expression of instinct, i.e. genetically coded behavior dispositions. This means that they have been, and still are, shaped by natural selection, and that adaptation occurs in these activities only between – usually many – generations. There are also some more rapid forms of behavior adaptations within the sometimes fairly broad limits left by what an animal is physically capable of doing. These adaptations are shown by the single organism, i.e. occur within one generation, as a result of reinforcement learning. Within very narrow limits, higher developed animals are also able to learn from observation of what their own kind are doing ('imitation'), speeding up the dissemination of better adapted behavior over what is feasible to mere reinforcement learning. However, in all these forms of adaptive behavior and, hence, the corresponding production, the underlying 'technology' basically remains the one determined by the inherited behavioral repertoire. Only among the most advanced mammals do the intellectual capacity and the capacity of the anatomic apparatus to do fine-tuned physical work jointly allow those animals to invent or discover and use primitive tools which they create from suitable materials.[15] Tool creation is a qualitatively distinct, and very rare, form of production in nature and a first instance of 'round-about' production which is not based on genetic but on phenotypic knowledge.

5 SOME IMPLICATIONS FOR PRODUCTION THEORY

Following the continuity hypothesis it has been argued that the study of production in nature allows the conditions under which early man started an own, cultural, evolution in production practices to be reconstructed. Moreover, the reconstruction, should offer some insights on – and thus should put in perspective – how human production has evolved since. Such an approach obviously differs substantially from the traditional a-historic interpretations and therefore also invites some reflections on the ontological presumptions underlying the theory of production in economics. The two issues may be discussed jointly by making five points.

First, one insight that can be gained from the suggested reconstruction relates to the theory of the factors of production. The naturalistic perspective just outlined suggests the question of what the "factors of production" in nature would be, if those factors are defined as the basic means by which all sorts of output are generated. Portrayed at a very abstract level (and abstracting from human manipulations for the moment), production in nature is based on two generic inputs. One is the inputs coming from inanimate nature which can be classified in two categories: matter or materials and free energy. The other is a self-generated and, qua novelty, *self-transforming* input which may be labeled 'knowledge'. More specifically, this is production knowledge in a literal sense, namely the accumulated genetic information about the particular forms of synthesizing energy and materials for keeping up the organisms' life function. The information is contained as a genetic blueprint in the form of DNA and RNA strings in the cells of the carrying organisms. The unique procedural property here is that the genetic information contains instructions to *uno actu* interpret and express the blue prints in the form of building up and maintaining the organism during its ontogeny. Because of the finite lifetime of the single carrying organism, the genetic code is transferred, with or without some recombinatory changes to the next generation of organisms, allowing for some adaptation of the code in response to natural selection influences.

The naturalistic interpretation of materials, (free) energy, and genetically coded, self-expressing knowledge as factors of production has little in common with what are traditionally considered the factors of production, namely labor, capital, and land. The reason seem to be differing theoretical interests. From its inception onwards, political economy interpreted production a *social* activity, rather than a changing technical one. Accordingly, concern was not so much with how products and services were generated, but rather with how they were distributed among competing claims. The corresponding key notion was that of separate property. Labor, capital, and land reflect the property aspect (while, from a naturalistic point of view, their technical relationship to the basic means of materials, free energy, and knowledge is a very complex one). The earlier background in moral philosophy may have invited the question of what kind of (re-)distribution of the fruits of productive activities could be considered legitimate.[16] Soon it was also recognized that the distributional problem has implications for the incentives to take part in the expanding specialization, division of labor, and market exchange of the upcoming industrial revolution. Accordingly, the problem of production was increasingly framed in terms of a theory about the proper imputation of value to both the (property in the) inputs required for production and the (property in the) resulting output – paving the way for an understanding of economics as the 'science of value'.

Second, a related insight that can be gained from the reconstruction of the conditions of production in nature is the following. The 'natural' production factors, materials, free energy, genetic knowledge were all in place when modern humans entered the scene. Hence, something had to be added for the (cultural) evolutionary change in human production to occur. The additional component, it is claimed, was a new form of knowledge, qualitatively different from the genetically coded, self-expressing forms involved in nature's production. (To indicate the difference, the new form is usually called cultural knowledge.) What powered the creation of the new form of knowledge was the already mentioned, unique combination of intelligence and fine-tuned motility which allowed humans to instrumentalize simple material objects found in nature as tools for better achieving productive purposes – initially the very same as pursued before. It is precisely by this transformation that a new form of evolution was triggered on earth: cultural evolution. Insight into the tool character of certain material objects is the first occasion in the evolution of nature where at least a vague intentionality comes into play, one which is alien to the genetic adaptation process.

With respect to the factors of production, cultural evolution has, thus, added just one new element. Besides the inputs materials, free energy, and (from a human perspective: given) genetic knowledge there is now another generated and, qua novelty, *self-transforming* input. This is culturally accumulated, anthropogenic production knowledge, emerging in ever new pieces which potentially disseminate and accumulate. During the evolution of human production from the early times on, the quantities of materials, of renewable free energy, and of genetic knowledge existing on this planet have by and large been unchanging. What has been changing is the growing share of these quantities put to anthropogenic use and, in the case of energy, the tapping of fossil energy deposits. These changes would not have been possible without the growing amount and quality of human production knowledge that has been actively generated, applied, and disseminated between generations. Hence, the accumulation of this factor seems to have been decisive for the pace of economic evolution. This is not a new conjecture in economics. It also figures prominently in new growth theory.[17] But since new growth theory is basically still a value theory lacking a 'naturalistic' foundation, the question it cannot answer is *why* human production knowledge plays this role.

Third, the naturalistic approach taken here offers an answer to precisely that question. Production knowledge and its continuing, cumulative creation has enabled man to achieve two things: (i) the increasing manipulation of nature's production process in the direction of human ends; (ii) the extending implementation and fueling of artificial, i.e., not naturally occurring, production processes. The first achievement is mostly based on an expanding symbiotic exploitation of other species in agriculture and the domestication and breeding of animals. The second achievement is based on the large scale creation and use of tools. It is more difficult and has occurred much later. Tool creation is almost always a transformation of materials. Such transformations require a controlled application of free energy in the form of heat, pressure, chemical energy, or kinetic energy by appropriate technical devices. So too, does the use of the tools. Thus, free energy has to be made available and proper devices (themselves tools) for transmitting and applying energy must be found.

For long time both requirements had to be satisfied by natural means whose limited availability imposed tight constraints on human production: human muscle power as the source of free energy together with the mechanics of the human anatomy extended by simple mechanical tools adapted to it. The burden of work was later transferred to the trained and supervised muscle power of domesticated animals – still a natural production process.

With the invention of the wheel, a mechanical device for power transmission and application not inspired by the model of human anatomy had been found. The benefits of the new tools were significantly increased when devices were invented to tap, i.e., transmit and apply, wind and water power to drive those tools. The introduction of the steam engine meant a real boost both in tool use and production volume, particularly when devices were invented that allowed fossil sources of free energy to be tapped (cf. Rosenberg 1982). Once made available, the new source of energy was quickly found to be also applicable to many other purposes, in particular for heating in the chemical processing technology which developed in the nineteenth century into a powerful, independent paradigm of transforming materials, cf. Buenstorf (2004). Another prominent application, based not least on chemical processing technology, is the conversion into fertilizers used to expand by orders of magnitudes the returns on the symbiotic productions forms.

All these dramatic transformations and expansions of anthropogenic production are difficult to account for in terms of a theory of production if that theory is tailored primarily to answer the question of how well the various recipients of the produced output (labor, capital owners, landlords) fare. The problem is not changed much by adding to labor, capital, and land an additional production factor 'knowledge' whose ownership structure is – because of the implied public good problem – admittedly more complex. Much of the accumulated anthropogenic production knowledge can only be 'expressed' by incorporating it in tools in the broadest sense. Hence, a large share of this is represented in what, for reasons of political economy, is called the real capital stock. But, of course, much more knowledge is necessary to run the production process. That knowledge is not 'expressed' in the tools, but in what people do when they create and use tools. In fact, the acquisition, expression, and creation of knowledge is today probably one of the most important services of labor. If economic theory is determined to stick to its traditional notions of the factors of production, the question may thus be raised whether it is indeed possible to identify an additional factor 'knowledge' independently of capital and labor.

Fourth, it seems indeed much easier to discuss the role of knowledge and to understand its particularities on the basis of suggested naturalistic approach than on that of the abstract standard production theory. Again a comparison of some characteristic differences between the genetically coded knowledge in nature and human knowledge is illuminating here. Genetic 'knowledge' comes in a form which *uno actu* interprets, expresses, and replicates its meaning in terms of blue prints for manipulating materials and/or triggering and controlling processes, provided the necessary materials and free energy are available. Replication occurs with some variation between generations, and since genetic novelty originates from those variations, the emergence of novelty is a part of the programmed automatism. None of this holds in the case of cultural knowledge. The latter is coded and stored in a form lacking an automatic copying, interpreting, and self-expressing modus. The generation, storage, expression (utilization and application), and even the replication of cultural knowledge all need to be effected by human action and require at least a minimal level of intelligence.[18]

For this reason alone, the evolution of cultural knowledge is much different from that of automatically self-expressing genetic knowledge. On the other hand, its reproduction and transmission is not bound to the rather slow inter-generational pace of the genetic replication mechanism in nature, but is based instead on inter-individual communication and individual interpretation. Accordingly, the technology of communication can be expected to have a crucial influence on both the quality of cultural knowledge and the pace of cultural evolution. In early man, communication was constrained to oral face-to-face interaction, instruction, and observational learning. Since this was also the only way of transmitting knowledge between the generations, accumulation of production knowledge was severely constrained. Consequently, there was comparatively very little development in tool creation, tool making, and tool use. This did change with the invention of alphabetic writing some four thousand years ago. With written documents, both storage and transmission of knowledge become largely independent of the personal contingencies of oral instruction and the bottleneck which the memory of the single instructor represents. Yet as long as writing and reading were confined to a small elite which used it less for purposes of production and tool development than for religious and regulatory purposes, the potential of the new communication technology was not fully used. Only with the invention of the printing press in the fifteenth century, and the subsequently developing broader literacy in Europe, could writings in science and technology achive broad dissemination.[19]

The boost of human production knowledge over the past two centuries and, consequently, the growth of human production thus seem to have to do with the significant changes in the technology of generating, storing, expressing, and replication of cultural knowledge. With a break-through in codification and dissemination techniques, a rapidly rising rate of literacy, the spread of formal education, and the organization and institutionalization of (re-)search for new knowledge in science, a soaring growth of mostly (but not only) useful knowledge has become feasible. Because of the limited capacity of the individual mind, this growth requires increasing specialization and division of knowledge. There is no doubt that the (re-)production of the respective body of knowledge in the mind of every new user and every new generation of users is itself a substantial part of modern human production which has changed dramatically the character of both the work being done in the economy and the quality of labor (cf. Witt 1997).

This development has recently been topped by an automatization of information processing, independent from the human brain, on the basis of electronic signal processing technologies. However, the reproduction of individual knowledge in command of this new technology in each new generation of students still has to rely on the old, inherited information processing technology of the human brain. As long as intelligence cannot be shifted to machinery, this is likely to be a hard constraint.[20]

Fifth, a point that may finally be raised relates to the question of whether and why the accumulation of human production knowledge can (at least temporarily) result in 'increasing returns' in producing output. New growth theory has postulated this as a feature of a production factor knowledge without, however, giving any reasons for it. In the perspective of the present approach a reason can be given. Mere acceleration of the generation and dissemination of production knowledge is not sufficient to bring about an increasing returns effect. What induces the effect is an auto-catalytic feature that may temporarily govern the development of production (Witt 1997). New production knowledge which makes tools and the means of fueling them available usually means a reduction in the working time necessary for carrying out production of the same output. Assume that, in a reorganization of production, the spare time and effort is used for increasing specialization. Under an institutional regime which allows an extended division of labor, 'increasing returns' may then become feasible.[21]

All that seems necessary is that specialization also includes the acquisition of specialized know how and skills that are employed, in turn, for systematic searching for, and developing of, further innovations in tool and energy uses. As long as the net amount of human labor saved by further knowledge creation is positive, production knowledge can thus 'breed' further production knowledge. This seems to be precisely the autocatalytic cycle characteristic of modern economic growth – at least for present. Indeed, how long such an autocatalytic cycle can be maintained is highly uncertain. This depends not least on the properties of knowledge generated in the future which cannot be anticipated. Even more uncertain seems to be whether the auto-catalytic features of modern knowledge creation will continue to imply a growth of the human economy as it is known today.

One of the reasons for this uncertainty resides in the fact that the strong growth of anthropogenic production knowledge has been accompanied by an increasing disintegration of cultural and genetically coded knowledge. The correlate is an increasing lack of integration of man-made flows of energy and materials (the 'industrial metabolism', cf. Ayres 1996) within the natural recycling flows. While the latter have been harmonized in evolution through inter-species competition in eco-systems, the former have, as mentioned, temporarily been freed from the constraints of natural selection. Human problem solving behavior in expanding human production activities has paid little attention to the fact that, in the longer run, these constraints will still be binding. At a closer look, human problem solving indeed often turns out to result in the creation of new problems. Problem shifting may, of course, result in problems piling up in the future. Ever more of future human knowledge creation may therefore have to be devoted to attempts at solving the problems created in the past and the present by the expansion of man's artificial production processes.

6 CONCLUSIONS

This paper has tried to clarify the notion of evolution in more general terms and to discuss its relevance for economics. An evolutionary, Darwinian, world view is now widely held in the sciences. What role does this play for economics or, to put it the other way round, what is the place of human economic activity in such a world view? The answer given here has been epitomized by what was called the 'continuity hypothesis'. In contrast to two other positions that have also been discussed – on the one hand the metaphorical, heuristic use of Darwinian concepts and, on the other hand, 'Universal Darwinism' – the present interpretation of the continuity hypothesis suggests the following. Evolution in nature as explained by (neo) Darwinian theory is one form in which evolution occurs in reality. It is domain-specific in the sense that this form is now the object of the discipline of evolutionary biology. However, evolution in nature anteceded the other forms of man-made, or cultural, evolution considered here and explored by other disciplines, e.g., linguistics and economics, in their respective domains. Therefore there is a historical, ontological continuity in which evolution in nature shaped the ground and defines the constraints for the various other forms of cultural evolution. Nonetheless, it has been argued that the mechanisms and regularities of cultural evolution differ fundamentally from those of natural evolution. Darwinian theory is therefore not sufficient to explain them. The many facets of cultural evolution require explanatory theories of their own.

Some of the implications of that hypothesis have been pointed out for the context of human production activities and their evolution over time. To identify the point at which man-made evolution intervenes, the mode of production in a natural state has been reconstructed in a more 'naturalistic' approach than the one usually pursued in economic production theory. A new factor of production – human (cultural) knowledge – entered the scene at that point in history. New production knowledge which emerges and disseminates incessantly in the human economy has driven the changes that have occurred since. It has been instrumental in bringing about the soaring growth in human production output. Some regularities and contingencies of the evolution of production have been discussed in the paper together with some implications for the economic theory of production. What had to be left out here for reasons of space limitations is the historical record of how production and consumption have interacted. The no less dramatic changes in consumption are an essential part of the economic evolution. The suggested continuity hypothesis should provide a basis for analyzing them in a way similar in spirit to the analysis of the evolution of production given here. The interpretation of evolution advocated in this paper may therefore be expected to be a fruitful basis for also inquiring into the interactions between evolutionary change in production and consumption – an important target for future research.

Ulrich Witt
Max Planck Institute for Research into Economic Systems, Jena
ulrich.witt@mpiew-jena.mpg.de

NOTES

1 Cf., e.g., Hermann-Pillath (1991), Rubin (1982), Robson (2001), Corning (2003). A modified version of this strategy has informed anthropological research under the label of the co-evolution hypothesis. It is argued that cultural behavior in primitive societies can be explained by the joint fitness value of genetic and cultural traits, cf. Durham (1976), Boyd and Richerson (1994).

2 An intermediate position was taken by the late Hayek (1982: Ch. 1 and 8) in his theory of cultural evolution. Focusing on the change of more basic rules of conduct and economic attitudes – which indeed vary very slowly – he denies natural selection a direct impact, but argues that the process of change may here mimic the effect of group selection. The conditions to be met for this to happen are: the cultural communities which collectively share rules and attitudes are separable, e.g. geographically; their differing rules and attitudes cause differential economic success; success differentials induce significant survival inequalities or migration processes between the communities. If communities with less efficient rules decrease in size and those with more efficient rules increase, then the underlying social traits change in their relative frequency correspondingly (where it is assumed that migrants can indeed switch in their attitudes and rules of conduct).

3 They portray firm organizations and their activities – production planning, calculation, price setting, and even the allocation of research and development funds – as being based on organizational routines (ibid., Ch. 5). Despite the obvious absence in the economic domain of anything comparable to genetic reproduction, the firms' routines are interpreted as 'genotypes' and the specific decisions resulting from the applied routines as 'phenotypes'. They are assumed to affect the firms' performance so that different routines which lead to different decisions also lead to differences in the firms' growth. On the further assumption that organizational routines which successfully contribute to growth are not changed, the growth of the firm effects an increase in relative frequency of those 'genes-routines' in the entire population of firms, i.e. the industry. The opposite is supposed to hold for routines causing a deteriorating performance.

4 Thus, firms are usually eager to identify deficient organizational routines and to replace or improve them in a kind of intentionally produced mutation of their 'routine-genes' before they fall victim to selection forces. In markets, the

effects of 'external' selection are therefore likely to be largely replaced by what would have to be called effects of "internal" selection in the form of deliberate strategic anticipation based on insight and intention. "Internal" selection may be the outcome of higher organizational routines as Nelson and Winter (ibid.) argue. But the higher the level of the organizational hierarchy at which a routine (the 'genotype') is employed, the more the decisions actually made (the 'phenotypes') are influenced by managerial discretion and, hence, the situational logic applied by the decision maker(s). The properties of the higher organizational routine and the idiosyncrasies of individual decision making may become equally influential so that any observed differential success can no longer be uniquely attributed to the higher routine involved.

5 If the difference is acknowledged, economic evolution may be interpreted as Lamarckian rather than Darwinian in character, cf. Nelson and Winter (1982: 11). As Knudsen (2001) explains, Lamarckian evolution here means that a direct feedback from the phenotypic performance to genotypic traits is allowed as a systematic feature. However, the benefit of constructing an analogy to Lamarckian evolution in economics is not clear. In the sciences, the Lamarckian theory has never been worked out so that its implications and dynamics are unknown.

6 It omits, *inter alia*, the principles of descent and speciation which are important parts of Darwin's theory, cf. Mayr (1991: Ch. 4).

7 Cf. Hayek (1967). In the history of evolutionary biology there is broad agreement now that some of Darwin's inspiration for his theory of the origin of the species by means of natural selection came from his readings of Adam Smith and Malthus, cf., e.g., Desmond and Moore (1991). The main focus of the writings of Darwin's very influential contemporary, Herbert Spencer (a co-editor of *The Economist* for several years) was also on the evolution – in the sense of 'progress' and 'betterment' however – of the human society and economy, cf. Bowler (1986).

8 Self-transformation may be taken as a synonym for 'change from within' as Schumpeter (1934) put it without apparently realizing the generic character for all evolutionary processes. Attributing a prominent role in economic change to novelty is now indeed common to all strands of evolutionary economics, cf. Hodgson (1995) and Dopfer and Potts in this volume. The connotations associated with novelty and innovations vary greatly, of course. In the above definition, the term "system" is just a dummy for the different disciplinary objects that evolve: nature in the case of biology, language in the case of linguistics, society in the case of sociology, or the economy in the case of economics.

9 The distinction between emergence and dissemination of novelty not only accounts for ontological differences. It is significant also for epistemological reasons because, by novelty's very nature, its meaning, and hence its future consequences, cannot fully be anticipated. For a discussion of the implications cf. Witt (1987: Ch. 1, 1993).

10 This co-evolution hypothesis figures prominently in the anthropological literature. For a statement of that hypothesis from the point of view of sociobiology cf. Lumsden and Wilson (1981).

11 The motivation to seek a better way of living is closely related to human wants and preferences which represent another, significant, co-evolving phenomenon that has been dealt with elsewhere, cf. Witt (2001).

12 The idea of setting economic production in perspective by comparison with the conditions in nature is not new. However, the comparison usually focuses on the implications of the laws of thermodynamics for theorizing about economic production, cf. Georgescu-Roegen (1971), Gowdy (1994), Faber *et al.* (1998).

13 For an exemplary rethinking of production theory in 'naturalistic' terms cf. Buenstorf (2004).
14 It may be noted in passing that under the influence of natural selection, i.e. driven by competition between the species in a given habitat or ecological system for reproductive success and an expansion of the own niche, production in living nature frequently effects substantial 'investments' in biomass which do not directly improve or expand the organisms' metabolism. Instead, these investments prevent the chances of the organisms of a given species from suffering in reproductive competition with other species, a phenomenon known as the 'red queen effect', see Stenseth and Maynard-Smith (1984).
15 Tools are defined as equipments which, as an outcome of an intelligent act, are created by, but not physically integrated into, an organism. The intelligent act at the origin of tools is what makes the difference to "investments" made by animals which, as discussed before, are guided by instinct.
16 This guiding interest is still very much visible in Quesnay (1736) and the physiocratic school. The school had a concrete understanding of the fact that the symbiotic forms of production in agriculture allow man (with the input of some additional human labor) to grow and reap the crops which themselves are 'produced' not by labor but by nature. Yet, the school's theoretical concern was to establish a theory of value which would explain whose property contributes how much to the overall expansion of wealth in the economy and what distribution of income could therefore be theoretically justified.
17 Cf., e.g., Grossman and Helpman (1991). New growth theory also postulates a more than linearly increasing functional relationship between human production knowledge – however measured – and output. On this see the fifth point below.
18 At least for its expression in tools, materials and the dissipation of free energy are needed as well. As in all cases of human action, the intention and understanding of the particular individuals involved also play a role for when and how cultural knowledge changes. These individualities, in turn, depend systematically on institutional features of the respective economies, cf. Witt (1987: Ch. 4).
19 With the printing press, the audience that could be instructed or informed could be multiplied. Since reading is a parallel process, information could much more rapidly be diffused than by spoken word.
20 Should ways be found sometime in the future to create a truly intelligent machinery, cultural evolution will have reached a stage in which humans are no longer in control of its outcome. The future fate of human production, indeed of the human species in general, may then hinge on whether the finite human problem solving capacity will be able to force the new intelligent beings into symbiotic forms of production of knowledge under human guidance or vice versa (cf. Wadmann 2001).
21 Drawing on Adam Smith, Marshall (1920, book IV) strongly emphasized this insight. Note that 'increasing returns' in this sense differ from increasing returns to scale. The latter concept is based on the notion of a production function defined over a set of factors of unchanging quality. In contrast, the very essence of the notion of specialization is that the quality of at least one factor involved in production changes. Increasing returns in the present sense has therefore sometimes been attributed to technical progress.

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