ADAPTIVE BEHAVIOUR AS THE MOST GENERAL FORM OF SOCIOECONOMIC BEHAVIOUR

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Introduction

This paper is based on the forthcoming book by Pier Paolo Saviotti and Morris Teubal, provisionally entitled 'Complexity and Economic Evolution: Innovation, Theory and Policy'. In the first two chapters of the book we point out that the existence of qualitative change in economic development leads to discontinuities and to radical uncertainty. As a consequence optimizing rationality is unlikely to have been usable during most of economic development, although that may be less true for some phases dominated by incremental innovations. As we previously pointed out, we think that neoclassical economics is based upon a series of foundations which, although useful to provide coherence to a highly formalized theory, make it unsuitable to analyze very complex situations and in particular the emergence of new economic species. We wish to avoid the confrontational attitude that rejects in its totality neoclassical economics and to adopt the point of view that its admirable elegance and deductive structure are achieved at the expense of excluding a large range of phenomena from its pursuit. In particular, we think that all phenomena involving qualitative change, foremost amongst which is the emergence of new economic species, are excluded from neoclassical economics by the same assumptions which make its edifice logically elegant and apparently all powerful. We will develop a general comparison of neoclassical and of evolutionary of economics as knowledge structures in Ch 6. Here we wish to compare two types of behaviour, adaptive and optimizing, which correspond to evolutionary and to orthodox economic theories respectively. As already pointed out, our objective is not to outcompete a rival theory but to contribute to the development of a general economic theory able to encompass both 'traditional' economic phenomena on the basis of which economic theories have been constructed and the innovation related phenomena which have been the basis for the construction of evolutionary theories. Here we will describe adaptive behaviour and show that it is the most general type of the two and that it includes optimizing behaviour as a special case.

In this chapter we discuss the nature and the limitations of adaptive behaviour and its applications to economic policies. In order to discuss adaptive behaviour we introduce some general concepts of systems theory that will be of use in this and in the following chapters.

2) Adaptation and systems

Adaptive behaviour can be defined as behaviour intended to improve some overall properties of the Socio-economic system (SES) that can range from welfare to rate of reproduction to production output to military might. Any theory of a given system must start by defining the nature of the system, then proceed by identifying the components and subcomponents of the system and finally by understanding the laws of interaction of these components. Such laws of interaction when applied to the components and subcomponents should explain why and how we observe particular patterns of development over the period we intend to study. The systems we will study are generally complex, including a variable number of interacting components, or subsystems, and are separated by an interface from their external environment (EE). The definition of the system itself and of its boundary with the EE is somewhat arbitrary and depends on the objective of our analysis. The most fundamental components of economic systems are human beings and a series of their aggregates, such as households, firms, hospitals, schools, governments etc. In this book the most common systems we will study are individual human beings and communities. By the term community we will mean here a group of individuals that has a shared set of, formal or informal, rules of behaviour and a defined boundary with the rest of the EE. When there is a change in the EE of a system in equilibrium with it, defined as a state in which neither the system as a whole nor any of its components have an incentive to change, we can expect the system itself to change in order to re-establish the equilibrium. We can say that the system in equilibrium was well adapted to its EE, that the change in the EE involved a loss of adaptation and that such a loss was likely to induce a change in the system's internal structure.

The system itself is generally complex, including a variable number of interacting components, or subsystems. The organization of the internal structure of the system consists of the pattern of interaction of its subsystems, that in turn determines its overall stability. Such stability is not indefinite and it is challenged by any change that occurs in the EE. Adaptation to such a change can sometimes occur by small and quantitative modifications of the system's internal structure, but in other cases more drastic changes are required. As already pointed out (Ch2) the boundary between qualitative and quantitative change is not always clear cut and sometimes over long periods the accumulation of small incremental changes within a given system can give rise to a new state of it which is clearly distinguishable from the initial one and which can be considered qualitatively different from it. Although this entails some ambiguity in the definition of economic species and makes more difficult to distinguish between transformations and transitions (Geels, 2002) (Ch 2) the twin characteristics representation (Ch 1) can help us to understand this difference.

The EE in principle includes all the rest of the universe outside the system. In most circumstances only a small minority of the components of the EE affect our system. In most cases it is enough to include in our representation of the EE only its most important components, some of which are other systems.

In some cases the interface between system and EE is discrete and clearly defined, in other cases it is fuzzy and possibly shifting in the course of time. For example, the legal boundaries of a city may be very clearly defined, but the real boundaries keep changing as new inhabitants arrive from elsewhere and settle in places not formerly within the city. Thus, in describing a system we must pay attention to the nature of its interface with the EE. We can then define the interface as the locus of change of the properties of the system, change that can be discrete or gradual.

2.1) System stability and change

A system comprising several interacting subsystems tends to acquire a *structure*, or a form of *order*, defined as a combination of its most elementary subsystems, which tends to be stable over relatively long periods of time. Some ambiguity in this idea stems from the fact that even the components are never identical to themselves at two different times. The whole system is continuously changing, although the various subsystems can with a degree of approximation be recognized to be the same across time. For example, the automobile industry is considered the same system from the beginning of the XXth century to the present, although many important changes occurred within it. We can only maintain that the system remains the same in the course of time by differentiating the fundamental aspects of the system from its secondary ones. We can then say that the system is the same at two different times if its fundamental subsystems are qualitatively unchanged. Thus, both quantitative changes in the fundamental aspects of the system and the emergence or extinction of some secondary aspects do not alter its nature (see box on the automobile industry). Obviously there is some arbitrariness in this procedure, but it allows us to study the evolution of systems and subsystems with a reasonable approximation. The stability of the system has been analyzed by means of several concepts, such as self-organization, homeostasis, self-regulation etc. Self-organization can occur at different levels of aggregation. Individuals self-organize in families, firms, associations and groups, firms self-organize in sectors and in industrial associations, cities self-organize in regions, regions in countries and countries in the international socioeconomic system. Amongst these levels of aggregation we can distinguish the lowest, or micro, the highest, or macro and a series of intermediate, or meso (Dopfer, Foster, Potts, 2004) levels of aggregation. In principle, there can be an almost infinite number of meso levels, but most of them are not meaningful. Thus, although ten or twenty people constitute levels of aggregation higher than one person, they are not a meaningful level of aggregation unless they are organized into a whole having a shared set of objectives, an internal division of labour and a clearly defined boundary/interface between the group and its EE. In other words, a meso level of aggregation is meaningful if it corresponds to the existence of a system having a definite boundary with its EE. Thus, ten thousand biological macromolecules or one thousand cells are not a meaningful level of aggregation unless the former are organized in cells and the latter in organs. A system is more than the sum of its parts, this more being supplied by the nontrivial pattern of interactions amongst its components. Thus, it is quite clear that the number and types of meso levels of aggregation are crucial in determining the overall, or macro, properties of the system.

Box 1: system sameness and the automobile industry

The automobile industry was born at the end of the XIXth century to produce a modified mail coach in which the horse(s) was substituted by an engine. In other words, the innovation consisted of a change in the mode of production of energy, previously supplied by an animal (horse) and now by a chemical reaction. The first automobiles looked more like mail coaches than like the modern ones. Modern automobiles share with the early ones some components but contain many new ones. Whether modern and early automobiles are the same entity depends on the importance we attach to the different components. If the definition is based only on the shared components then modern and early automobiles are the same entity, otherwise they are two different entities. Alternatively, we can define automobiles as artefacts that supply transport services (Ch 1) without the intervention of an animal source of energy. However, in this case automobiles would be part of a more general category, including trains, buses and airplanes. Thus, whether today's automobiles are different from the early ones and whether the automobile industry is still the same depends on our classification criteria. This situation is not specific to the automobile industry: most industries and presumably most human activities keep changing in the course of time in ways that are not purely quantitative, but that we do not consider qualitative changes leading to formation of different industries or activities. Again, we could consider that the automobile industry is still the same but that it has been undergoing important transformations or that within it there have been important transitions and that it is no longer the same industry. Once more, the distinctions between qualitative and quantitative change or that between transformation and transition depends on the aspects of the SES that we predominantly focusing upon.

2.2) System dynamics

An SES is never static and keeps changing. This can be due to exogenous or endogenous factors. An example of the former is the formation of the Sahara desert from the fertile region that seems to have existed at some time in the same part of Africa. Endogenous transformations in general entail some innovation. One of the earliest examples of an endogenous change is the advent of settled agriculture from the society of hunters and gatherers (Gowdy, 1994). This was based on a long learning process by means of which some groups of human beings discovered that some plants could be cultivated and some animals could be domesticated (Diamond, 1997). Such a discovery allowed human communities to overcome the seasonal character of some fruits and vegetables and to use domesticated animals as source of food and energy. Such a transition allowed human beings to increase their efficiency of food production, thus liberating some of their human resources for other uses. This was the beginning of the differentiation of human societies. This transition was endogenous in the sense that it came from within the SES and it was not forced upon it from outside the system. We could say that this transition was based on a form of 'learning by doing'. Changes arising within modern SESs can occur in a more consciously purposeful way. A different and historically more recent form of learning is constituted by R&D, or by its generalized analogue, search activities (Nelson, Winter, 1982). In principle all human activities can be reduced either to *routines* or to *search activities*, where the former are standardized types of behaviour adopted by individuals or organizations in response to demands coming from components of their same system or from their EE. Routines are changed infrequently and only when a change in the EE renders them unusable. On the other hand search activities scan the EE about a given subject trying to understand the laws governing our natural environment and using this knowledge to (i) reduce the amount of resources required to achieve some productive objectives or (ii) to suggest ideas for new products, processes or organizational forms. As opposed to learning by doing, search activities can be considered a form of *learning by not doing*. This form of learning is relatively modern since it became institutionalized only in the second half of the XIXth century and it diffused generally only after the second world war.

Innovation occurs when some changes are introduced into existing ways of doing things, be they physical processes or organizational arrangements, or when completely new goods or services are created. Innovations can affect in different ways the *stability* of a system. They can improve the efficiency of existing processes or give rise to new goods and services. They can then contribute to the growth of the system and to its changing structure. The detailed ways in which this occurs will be analyzed in Ch 4. Here it suffices to say that the effect of innovations is to change the 'size' and the nature of the system. The nature of the system changes as new sectors, qualitatively different from pre-existing ones emerge. Growth in the 'size' of system can occur both because new sectors add new markets to pre-existing ones and because increases in productive efficiency can allow pre-existing sectors to grow either in volume and/or in value. These mechanisms will be explored in a more detailed way in Ch 4. Innovation is one of the most powerful forces moving the system away from any position of equilibrium it might have attained (Schumpeter,1911,1934). Once an SES starts using innovation and allocating to it resources it has condemned itself to be in a state of permanent instability (Metcalfe, 1998). If the technology life cycle identified in the previous chapter, starting with a radical innovation and gradually moving to a more predictable stream of incremental innovations, is followed we can expect instability to go through different phases, ranging from the construction of new system components (e.g. new training, education, complementary institutions)or to a gradual increase in their productive efficiency. As the most innovative system in history 'restless capitalism' (Metcalfe, 1998) creates permanent instability. An aspect that we will stress heavily in Ch 4 is the differential rate of change of different components of the SES that will give rise to a change in the structure of the same SES.

2.4) Closed and open systems

A distinction of the greatest importance for biological and socioeconomic systems is that between closed and open systems (Prigogine, 1947; Prigogine, Stengers, 1984; Von Bertalanffy1950; Hidalgo 2015; Beinhocker 2007, Haken, 1983). The former are separated from their EE by an interface that does not allow the passage of matter, energy or information. A closed system tends to achieve an internal equilibrium characterized by the maximum possible disorder of its components. On the contrary, an open system has boundaries that allow the passage of matter, energy and information. Open systems can differ for the rate of flow of matter, energy and information across their boundaries. In fact, this rate of flow constitutes a measure of the distance of the system from equilibrium. Contrary to closed systems, open systems have the remarkable property that they not only do not tend to give rise to states of maximum disorder but can create states of increasing order. This property was crucial in demonstrating that the existence and nature of biological systems did not need the presence of a vitalistic component. Furthermore, the evolution of SESs does not give rise to continuously increasing disorder but to more ordered, if more complex, structures. The order characterizing both biological and socioeconomic systems can be explained by their nature of open systems.

Like biological systems SES are characterized by a high degree of order and complexity, which is likely to have increased in the course of human history. Components of SESs, such as firms or organizations, are open and have continuous flows of matter, energy and information crossing their boundaries. An interesting example of this open nature is given by the work of Alfred Chandler (1962, 1977) who suggested that changes in the structure of a corporation could be induced by the increasing throughput crossing its boundary. The increasing labour force required to use such a rising throughput needs to be organized hierarchically with a growing number of levels. The same principle can be expected to apply to hospitals, schools, and other types of organization. Without going into greater details it is clear that existence of open systems is crucial to explain the observed pattern of economic development.

3) Adaptive Behaviour

The concept of adaptation is used in a number of disciplines and research areas, such as biology, ecology, psychology, computer science, climatology. Although the definitions used in the different fields vary they have something in common. For example, in behavioural ecology an **adaptive behaviour** is a behaviour which contributes directly or indirectly to an individual's survival or reproductive success and is thus subject to the forces of natural selection. Conversely, a **non-adaptive behaviour** is a behaviour or trait that is counterproductive to an individual's survival or reproductive success. In a more general sense we can define adaptation as a change of behaviour of an entity living/operating in a given external environment (EE) aimed at improving the survival of the entity or some other objective. The entity itself can be a biological organism, a human being, an algorithm, or a community at different levels of aggregation.

We can extend this concept to the study of economic development by introducing some modifications. The definition of adaptive behaviour requires a system, its EE and an interface between the two. Let us start with a system in a state of equilibrium with its EE, in such a way that there is no 'force' or tendency leading the system to change. Then, if a change, which for the time being we can regard as exogenous, occurs in the EE, such equilibrium will be destroyed. We can then expect the system to try to re-establish a state of equilibrium by changing something within itself. As a consequence we can expect that when the new equilibrium is eventually attained the state of the system will be different from its initial pre-perturbation state. If the system is a human being or an organization we can expect it to change its behaviour to re-establish a state of equilibrium. For example, if it starts raining we can expect human beings to take refuge in a dry place or to use an umbrella. Likewise, if the price of a particular input rises we can expect firms to reduce the quantity they use. If the change in the EE is just a shock, that for the moment we consider exogenous, then after the adaptation of the system the equilibrium is re-established. Things would be different if the perturbation instead of being a discrete shock acted continuously in the course of time at a given speed. In this case the process of adaption would be more complex, the outcome depending on the relative speeds of perturbation and of system adaptation. We will shortly come back to this dynamical problem in discussing the existence of a general equilibrium. Before doing that we need to articulate better the concept of adaptation.

3.1) ADTO and ADOF

In the previous examples adaptation was defined as a change of behaviour of the system required to re-establish equilibrium with its EE after a perturbation occurred in the latter. In human communities a second type of adaptation is constituted by the deliberate introduction of changes in the EE intended to improve the future adaptation of the community to the modified EE. The construction of roads, houses, bridges and airports are examples of such adaptation. This form of adaptation occurs also for some biological species, such as termites, ants and bees, but at a much lower scale than for human communities. In fact, this second type of adaptation has become so widespread that its impact on the on the EE has become of the same order of magnitude as that of natural phenomena, giving rise to what is now called the Anthropocene (ref). In what follows, to avoid repetitions we will distinguish between adaptation to a given EE (ADTO) and adaptation of a given EE (ADOF).

Summarizing, we can distinguish two types of adaptive behaviour :

(i) Adaptation *to* a given EE [ADTO]

(ii) Adaptation *of* a given EE = transformation of EE [ADOF]

where (ii) involves the modification of EE and its transformation into EE' EE.

The fundamental difference between ADTO and ADOF is that the former only involves a change in the system while the latter involves a change in the EE which needs to be followed by an ADTO to the modified EE. Any form of ADOF involves some type of innovation. Innovations were very infrequent in ancient SESs but have become the norm in modern ones. Change is then endogenous to the extent that it requires the decisions made to be internal to the system. In the course of time innovations are accompanied by a process of learning and of accumulation of knowledge that can lead to more and larger scale innovations.

When the EE is changed by ADOF the system will not be immediately adapted to the new EE (EE'). The process of ADOF can be represented as a human community operating on a given EE and transforming it into a different one:

HC (EE)   EE'

The human community will now need to adapt to (ADTO) to the new EE (EE'). This will have very important implications for the dynamics of our system.

In principle both ADTO and ADOF can exist for both biological and human populations, but ADOF is much more developed in socioeconomic systems than in biological ones. The types of nests that some animals (e.g. bees, ants) can construct are indeed very elaborate and can qualify as ADOF *of* a given EE. However, their scale and variety does not match that of human artefacts and infrastructures. The term anthropocene has recently been introduced to describe an era in which the scale of the impact of human activities on the EE matches that of natural phenomena (ref, Economist). A similar scale had never been achieved by any biological system. However, it is not just the scale of the type of adaptation that differs between socioeconomic and biological systems. The objective of adaptation is much more narrowly defined for biological than for socioeconomic systems. Whereas for the former the objective of adaptation is survival or reproductive success such objective can be far more varied in socioeconomic systems. For example, the fall in the rate of population growth in modern industrialized societies cannot be interpreted as an increasing maladjustment of these socioeconomic systems to their EE. Although this fall in the rate of reproduction seems to be in stark contrast to the observed behaviour of all biological systems in the course of history, it is in fact the result of a change in the objective of adaptation. In a modern industrialized society it is preferable to make fewer children but to give them a better education than to make many children endowed with very poor capability to adapt to such a socioeconomic system. The required education cannot be given to any number of children because it is very costly. Furthermore, the need for large families is less pressing in a modern industrialized society due to the presence of various forms of social assistance, ranging from health care to the care of the elders. These new forms of social assistance transformed the objective of adaptation. In other words, the previous evolution of the socioeconomic system gave rise to new institutions (education, health care, pensions) which induced a change in the objective of adaptation. These new institutions were endogenous to the socio economic system because their emergence was induced by previous changes in the same system. The objective of adaptation is likely to have remained substantially constant for biological systems, or if any changes in the EE occurred they would have been exogenous to such systems. Summarizing, we could say that for socioeconomic systems the objective of adaptation is likely to have undergone changes due to the endogenous evolution of such systems, while for biological systems the objective of adaptation is likely to have remained substantially constant with the possible exception of exogenous changes in their EE. This difference reflects the growing importance of the manmade component of their EE for socioeconomic systems. The emergence of new types of ES1s is one of the most important forms of ADOF. As we will see in Ch 4, new ES1s never exist in an otherwise unmodified system and EE. As we will see in Ch 4 in order to grow and to diffuse they need the construction of complementary infrastructures and institutions in a co-evolutionary process.

3.2) Collective and individual adaptation

Another very important difference between biological and human evolution is the much greater collective nature of human adaptation. Forms of collaboration occur also amongst biological species but they never reach the organizational complexity existing in human societies. Group behaviour is observed amongst animals but such groups are much smaller and less complex than those observed in human societies. The fact that societies of large size and great complexity exist is a proof that collective adaptation is superior to individual adaptation. Robinson Crusoe could never compete with any kind of organized society. Such superiority of collective adaptation is due to the possibility to develop within a group forms of division of labour and coordination. Here the division of labour is not limited to production activities but it is extended to all functions in the community, including judges, doctors, lawyers, traders, teachers, etc. Specialization in particular tasks, which was initially mostly related to the procurement of vital resources, increases their efficiency thus freeing a part of human labour which could then be applied to other functions. Thus, the transition to settled agriculture enhanced the efficiency of food production and contributed to the differentiation of human societies (Diamond,1997; Lipsey et al, 2005). Although the majority of the population was still engaged in food production new activities could be introduced: priests, traders, warriors became recognized functions in human societies. We can start here observing what will turn out to be a general point in economic evolution: the growing efficiency of existing activities can free resources, in this case labour, and induce the emergence of new activities.

For all its power to enhance the efficiency of human activities division of labour could not improve collective adaptation alone. To do that it needs to be combined with coordination. In the same way as in a productive process, if the outcome of a given stage is not coordinated with the other ones, the overall process does not produce any desirable outcome. If workers in an assembly line do not do their job the process cannot proceed. If teachers stopped teaching, social life as we know it could not continue. As a consequence collective adaptation is superior to individual adaptation. Furthermore, societies which have a 'better' system of division of labour and coordination tend to outperform other societies which less advanced systems. This implies that group selection operates at the level of human communities and societies.

The overall organization of division of labour and of coordination in a society is not explicitly decided by any individual but slowly created in the course of history. Individuals in a community differ in a number of aspects. For example, they can differ for their strength, intelligence, education, competencies, wealth etc. In a modern society inter-individual differences are also heavily influenced by education and training. Furthermore, these differences determine and are determined by the place in the overall division of labour that individual members occupy in the community. The coordination of the behaviour of individuals is largely determined by institutions, themselves defined as sets of rules. In the mean time, inter-individual coordination in a community involves the mutual adaptation of individual members to one another.

The heterogeneity of the capabilities and of the tasks carried out by individual members contains the roots of the distribution of wealth and power in a community. Such tasks can be expected to vary in importance and therefore in the value which is attached to them in the community. The existing set of institutions is likely to reflect to different extents the existing distribution of wealth and power in a community. Typically, in all real socio-economic systems there are elites which concentrate a much larger share of wealth and power than the less privileged members of the same systems and have a greater influence on the construction and maintenance of institutions. Communities can differ for the extent to which institutions are designed to take care of the general interest of all the members or of those of elites. The distinction between extractive and inclusive institutions (Acemoglu, Robinson, 2012) reflects the extent to which institutions allow the entry or the upward mobility of less privileged strata of society (here see also A. Deaton in What if? Economist, July 2017). Thus, coordination completes division of labour and allows human societies to enjoy their capacity to give rise to growing efficiency and creativity. We will discover later that even growing efficiency alone is not always advantageous.

The advantages of communities came at a price. Communities never included all possible human beings but were groups of limited size, although such size tended to increase in the course of history. By definition a community needed criteria of inclusion and exclusion. It was important to know who was a proper member and who was an enemy. These criteria could be based on language, religion, or physical features such as skin colour. Furthermore, rules were intended to encourage collaborative behaviour within the same community and rivalrous behaviour between the members of different communities. Modern conceptions of intolerance find their antecedents in the exclusion criteria required for the formation of ancient communities. Hence people are not intolerant or racist because they are bad but because to be able to exclude members of different, enemy, communities has always been part of inter-communal life. These considerations cannot be interpreted as an attempt to legitimate intolerance or racism, but as an extension of attitudes which up to a point were considered legitimate or even to be praised (see the hate for enemies taught to soldiers even to athletes in some sports and its extension to the hate of the "'other'' in intolerant or racist movements). Tolerance and human rights are human inventions which go against millennia of intolerant behaviour rooted in the life of communities.

3.3) Adaptation, stability and change

The previous considerations could be interpreted as implying that once a society has achieved a 'good' adaptation to its EE and of its component members to one another, nothing more would happen. We could say that a state of equilibrium would have been attained in which there would be no inducement to change coming from within the same society. However, such extreme stability is unlikely to be ever attained. No existing society is without internal tensions and contradictions. In particular, innovation is a destabilizing force which could shake up any equilibrium that were temporarily attained. Of course, innovation is by no means the only factor that could create instability and lead to change. Other factors can be a source of frustration and of suffering for some members and groups in society who feel that they have been unfairly treated. For example, the distribution of income and power have been or are being perceived as unjust in the industrial societies of the XIXth century or in the post industrial societies of the XXIst century. Even when there are no particular grudges about injustices or sources of suffering there is always a general tendency of human beings to improve that had already been observed by Adam Smith who wrote that 'the desire of bettering our condition comes to us from the womb, and never leaves us until we go into the grave' (1776, p. xx, cited in Friedman, 2010). We could then consider human beings *adaptive improvers*. It could be argued that adaptive behaviour is not specific to human beings but that it occurs also amongst animals and plants. However, the extent of adaptation *of* a given EE is likely to be much greater for human beings than for any other animal species. As a consequence we will consider that human actors, or agents, are adaptive improvers. This does not imply that all human beings are continuously searching for improvements in their situation. In fact, many people are rather averse to change. The statement that people are adaptive improvers needs to be applied to the level of the community. Communities differ as to the percentage of their members who are searching for improvements in their situation and are prepared to take the risks that this involves. Such a percentage is not constant but varies with the institutions and the knowledge base of a community. Schumpeterian entrepreneurs are perhaps the best example of adaptive improvers and we do not expect to find them with the same probability in different communities: Silicon Valleys are not uniformly distributed all over the world. The existence of adaptive improvers depends on the inducements, resources and rewards that a community can provide for them. In the end the probability of finding adaptive improvers depends on the institutions of a given society.

In modern societies adaptive improvements come largely from innovation. Most innovations lead to changes in our EE, either in its physical or in its social component. Thus, innovation leads to ADOF. Whenever an innovation changes the EE of a society to a different one EE', the society is not immediately well adapted to the new EE'. The process of adaptation to the EE' (ADTO) can in some cases take a very long time. Innovations like railways, cars, electricity or computing were introduced and adopted fully during periods of tens or hundreds of years covering several generations. During these periods SESs are subject to inducements to changes leading to the further incorporation of innovations in society. These periods cannot in any sense be considered as being of equilibrium intended as a complete absence of change. At best we can think about them as periods in which the future development of the system (SES) corresponds broadly to *expectations* that have been formed in the initial phases of an innovation. We will refer to the complete lifecycle of an innovation, called technology life cycle (TLC) as the period going from the *emergence* of the innovation to its complete diffusion, corresponding to the *saturation* of the SES. We realize that such definition is oversimplified since some lifecycles can be more complex than that. We will initially use this simplified form to describe our viewpoint and add later more complex situations. As it was pointed out in Ch x the life cycle of subsequently add further complexity. In general pervasive (Freeman) innovations begin with an initial period characterized by radical uncertainty and proceed with a subsequent phase of more predictable incremental innovations. The latter phase of the life cycle can correspond to periods of high and stable growth. However, balanced growth does not correspond to an equilibrium in which nothing changes but to a situation in which things can grow according to expectations, or change occurs mostly quantitatively.

The dynamics of an SES can then be analyzed at a more aggregate level, as that of the whole system, or by taking into account the interactions of its different components. If we first consider the whole system, the emergence of an innovation creates a future hypothetical state of the system which can become the source of investment, planning and action. This hypothetical state of the system acts as an attractor towards which the system tends to move. The transformation of an SES from its real state to the hypothetical one defined by the innovation can take a long time.

Then, in presence of innovations the dynamics of human development will be constituted by a sequence of ADOF and ADTO in which the creation of a new EE by means of ADOF will always be followed by the process of adaptation to this new EE by means of ADTO. The corresponding processes occur at *finite* speeds and the outcome depends on the relative speeds of different component processes.

We can now place the previous considerations in a more analytical format to show that in a system which is continuously innovating a general equilibrium can exist only in special circumstances. Let us start with a system S that is initially in equilibrium with its external environment EE. We can consider this a general equilibrium and represent it as $(S_0, EE_0)^*$, where S_0 and EE_0 represent the states of the system and of its external environment in the equilibrium situation. Let us now assume that an important, radical innovation emerges within the system S. This innovation can be expected to create a new product or process technology, a new organizational form or a new market, and to modify the external environment EE transforming it into a different one. At its emergence the new technology is just a broad and not perfectly defined idea, at best accompanied by few prototypes. This starts a co-evolutionary lifecycle in which the new technology is produced in an initial form, the required investment is obtained, complementary institutions and infrastructures are constructed and the technology itself is gradually modified. The previous changes modify the EE. Both the extraction of new materials and the building of infrastructures modify the natural environment. Moreover, new institutions need to be created and existing institutions to be modified. Clearly, the effect ofthe innovation cannot be instantaneous. The transition necessarily occurs at a finite speed in a finite period of time. Thus, the innovation has destroyed the equilibrium represented by the state (S_0, EE_0) since the system S in its state S_0 is no longer adapted to the new state of the external environment. The innovation destroyed the initial state of equilibrium and created an imbalance between the present state of the system and the hypothetical state that would be adapted to the new state of the external environment. This imbalance is likely to be greater the greater the difference between the 'real' state of the system and its hypothetical adapted state.

As the innovation goes through its lifecycle the state of the EE keeps changing gradually. Meanwhile the system is subject to a continuing imbalance depending on the relative rates of change of the system S and of its EE. Let us try to simplified cases:

Case 1) An innovation is created perturbing the initial state of equilibrium (S_0, EE_0) and inducing transformation of EE_0 into EE_1. In this case the innovation once created remains unchanged

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Innovation, ADOF system adaptation, ADTO

(S_0, EE_0) (S_0, EE_1) (S_1,EE_1)

(R_S, R_{EE}) (R_S, R_{EE})

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where S_1 is the state of the system adapted to the new state of the external environment EE_1, RS and REE are the speeds at which the states of the system and of the external environment move towards the final state (S_1,EE_1). Such a state could be considered a new general equilibrium. Even in this oversimplified case the time required for the system and its EE to go from the initial to the final equilibrium state could be extremely long. All the intermediate positions and times correspond to non equilibrium states of the system and of its EE.

The previous case was clearly oversimplified since no important innovation ever remained unchanged in the form in which it was initially introduced. Clear examples are the train, the car, the airplane, the computer etc. In this case the final state (S_1,EE_1) might simply not exist. Then all the subsequent states would be non equilibrium states characterized by different degrees of imbalance.

Case 2) In this case the initial emergence of the radical innovation giving rise to one or more new sectors is followed by a stream of incremental innovations that will modify the innovation itself and the EE. Then the combined state of the system and of its external environment is likely to change continuously wit different degrees of imbalance, where imbalance is a measure of ill adaptation ord from the equilibrium.

Innovation (t0), ADOF Innovation (t_0+ t=t_1) Innovation (t_1+ t=t_2)

(S_0, EE_0) (S_0,EE_1) (S_1,EE_2) (S_2,EE_3)

Equilibrium Imbalance Imbalance imbalance

(R_S, R_{EE}) (R_S, R_{EE}) (R_s, R_{EE})

In this case the combination of the system and of its external environment never reaches an equilibrium except in the special case in which the speed R_S of adaptation of the system is much greater than the speed of change R_{EE} of the external environment. Based on historical examples this situation seems to be very rare.

3.4) Fitness

The previous considerations can be expressed in terms of fitness. Fitness is a measure of the adaptation of organisms, species, individuals, communities or technologies to the environment in which they live. Fitness is specific both to a given EE and to a given objective function. Thus, an organism that is very fit in a given EE can be very unfit in a different one. Likewise, an organism or a community which is very fit with a given objective function can become very unfit if the objective function changes. As we have seen for the example of the falling rates of reproduction, the objective function of fitness can change from making many children to making few and educate them, due to endogenous transformations of the same industrialized socioeconomic systems. Thus, an important difference between socioeconomic and biological systems is the much greater range of endogenous changes which can occur in the objective function of fitness of the former as compared to the more limited and exogenous changes for the latter.

The concept of fitness is intimately related to that of natural selection (ref). For biological systems genetic heritage favours some individuals or species which tend to become relatively more abundant in the course of time. For socioeconomic systems there is no precise analogue of genetic heritage, but learning and knowledge become progressively more important in the course of human development. Thus, the fitness of modern socioeconomic systems can be expected to depend on their knowledge, which in turn depends on their mechanisms of learning. Although forms of learning by doing are not unknown for other biological species, they have never achieved the importance and the scope that they have for socioeconomic systems. Thus, a very important difference between the evolution of biological and of socioeconomic systems consists of the much greater relative extent of ADOF with respect to ADTO for the latter with respect to the former. In turn, the higher ratio ADOF/ADTO depends on the role that knowledge and institutions played in the evolution of socioeconomic systems. One of the most important mechanisms by means of which the

3.5) Barriers to adaptation

Part of the previous discussion could have given the impression that the change in behaviour required for adaptation is self-evident and that the only problem consists of carrying it out. That is not the case in general. We have already seen that the objective of adaptation is much more complex and possibly changing endogenously in the course of time for socioeconomic systems (SES) than for biological systems. Furthermore, in many cases the change in behaviour required to adapt is not known at all or we know only the aspects of the system we want to change but we do not know with what conditions to replace them or how to do it. For example, if some phenomena indicate that human activities start affecting in a non sustainable way our EE then we need to reduce their impact. Even assuming that everyone shares this objective, there are a very large number of ways of attaining it, each one of them very imperfectly known. Furthermore, even if the costs and benefits of one adaptation strategy were perfectly known, its advantages and disadvantages would likely be unevenly distributed across the world SES. A general feature common to this and many other examples is that we tend to react to a situation that we find unjust or dangerous, and thus in need of change, but that we do not know how to change or cannot collectively do it. In other words, any adaption strategy faces at least two types of barrier, a cognitive and a political barrier. The former arises because sometimes the changes in the EE are not adequately perceived or understood. For example, more than fifty years after the impact of human activities on the EE started to be perceived (ref) there still are conflicting interpretations of how that is occurring or of what can be done to avert its inherent dangers. As already pointed out, such limited understanding is an inevitable feature of the emergence of important and radical innovations. In addition to the cognitive barriers, the adaptation to some changes in the EE can be opposed by existing vested interests or it is likely to follow a different path depending on the nature of the institutions existing in a particular society. For example, groups carrying out activities with a high impact of the EE from which they were deriving their wealth and power are likely to resist or to slow down attempts to limit such impact. Furthermore, even when a general agreement exists within a given society about the need to change some rules in order to adapt to changes in the EE, the outcome of these rule changes is likely to differ depending on the institutions pre-existing in such a society. According to North (1990, p. 101) adaptation can only exist at the margin.

3.5.1) Cognitive barriers.

Cognitive barriers exist because important innovations are always created in a state of incomplete knowledge. In fact, we expect entrepreneurs to conceive an innovation having only a broad idea of the innovation itself but to be generally incapable of defining with any accuracy the actual form the innovation will take. That can be true at different levels of aggregation, ranging from an economic species of type 1 (ES1) to that of a whole SES or even of a long term trend such as industrialization. n Uncertainty about a given ES1 arises both in a technical sense, as early innovators in cars or telephones could not conceive the precise form these artefacts would take, or in broader sense as such ES1s did not develop in a vacuum but needed many complementary infrastructures or institutions. Furthermore, uncertainty arises about broader trends, such as the relationship between human activities and the natural environment. In fact, we have already referred to the incomplete knowledge on the basis of which entrepreneurs create major innovations as entrepreneurial knowledge. As already pointed out, entrepreneurs create innovations in an initial form which is subsequently improved by a string of incremental innovations, which advance both the services supplied by the innovation (Ch 1) and the knowledge surrounding it. The uncertainty surrounding major long term trends is likely to be even higher than that referring to individual innovations. Examples of these trends could be industrialization or the impact of human activities on the natural environment.

3.5.2) Political barriers

In a general sense political barriers are linked to system configurations that have been created within SESs in the past. The ownership of land or the differential access to military power have from the very far past constituted the basis for the domination of society by particular groups. Since the beginning of the industrial revolution the new social classes of the industrial bourgeoisie and of the proletariat have emerged. The combination of these groups, of the activities they carry out, of the new or modified institutions that accompany their emergence, define a configuration of the SES that can be stable for long periods of time. Any social group trying to improve its share of resources and its status is likely to face a barrier due to the possible attempt by previous dominating groups to protect their status and power. We can expect resistances of this type to be stronger in a society in which the resources available are fixed and in which as a consequence competition from emerging groups occurs according to a zero sum game. On the other hand, an SES which can create new resources, thus leading to an increasing sum game, or that is politically inclusive, can provide an easier entry for emerging social groups. The variety of situations in which such political barriers can arise and impede adaptation is very large.

The existence of barriers of these types explains why sometimes particular social groups, regions or countries do not adapt to changes in the EE which seem to require adaptation. In general an adaptation strategy is likely to emerge by a process of decision making involving a series of stages, going from the perception and understanding of the change, to the formulation and implementation of the strategy itself. Processes of human decision making are in general based on incomplete knowledge and affected by existing configuration of

SESs. Furthermore, even when particular adaptation strategies are implemented and are successful in attaining their initial objective, they may transform the EE in ways that replace the previous problem with new ones. In the following boxes we will analyze some examples that will make more concrete the previous general considerations.

Box2: pensions

The achievement of pensions during the XXth century was a progressive institutional change. Recently, as a consequence of changes occurring in related aspects of the SESs of most industrialized countries, the funding of pensions has become a growing problem. Increasing life expectancy, itself due to improvements in nutrition, hygiene and health care, and falling birth rate have both prolonged the period that the average individual spends in retirement and reduced the ratio of people of working age to that of retirees. Furthermore, people tend to be relatively healthy and capable of carrying out purposeful activities beyond retirement age (Economist, 2017). As a consequence a combination of raising costs, falling resources and poor utilization of human capital has been created.

During the period since its creation there has been a transformation of the meaning of retirement as well as of the meaning of work. What was perceived as a form of justice eliminating old age poverty became contested terrain due to changes occurring simultaneously in other aspects of the SES. As previously pointed out, such changes are Increasing life expectancy and falling birth rate, the combination of which has increased the costs of pensions (people spend a larger share of their lives in retirement) and reduced the resources required to fund pensions (the ratio of the number of working people supporting pensioners to that of pensioners tends to fall). Furthermore, the health and human capital of the average retiree has improved due to progress in education and health care. Although heavy and potentially dangerous occupations still exist for which early retirement would be appropriate and well deserved, a large number of retired people is capable of carrying out complex functions (Economist, 2017). Furthermore, work provides both income and identity, both of which could be enhanced for retired people by their continued involvement with purposeful organized activities. Such involvement would not necessarily be full time but it could be modulated to combine income from work and income from pension, with shares varying in the course of time to suit individuals' preferences and capabilities. For example, working time could be gradually reduced and the falling income stream could be supplemented by an increasing pension share. A solution of this type, consisting of a three pillars system, has been proposed by the Geneva Society (2005). The first pillar is a pension of the present type, the second is additional personal savings, the third pillar is an income stream from working activities.

Although Increasing life expectancy and falling birth rates have been operating at least since the 1970s reforms of the pension system aimed at reducing its potential imbalances have been introduced only since the late 1990s. Such a situation can be interpreted as a lack of institutional adaptation. Increasing life expectancy and falling birth rate can be easily observed, and an adaptation of pension regimes could have consisted of raising pensionable age in parallel with life expectancy. Furthermore, the advantage of better health after retirement can be exploited by defining working conditions appropriate to the corresponding age. Although Increasing life expectancy and falling birth rates have been operating at least since the 1970s reforms of the pension system aimed at reducing its potential imbalances have been introduced only since the late 1990s. Furthermore, reforms of the pension system going in these directions are now underway in a number of countries, but they encounter different barriers. For example, to raise the pensionable age has proved to be more controversial in France than in other European countries. Thus, the need for adaptation is perceived relatively slowly everywhere and it elicits adaptive responses which can differ markedly amongst different countries. In a long term perspective pensions, which were introduced to reduce old age poverty, have at least partly attained this objective (see OECD 2015) but have created new contradictions and problems.

Such a situation is by no means unique for pensions but shows some common features with other types of human decision making. First, the knowledge used in human decision making is generally incomplete and our ability to predict the future impact of such decisions is extremely limited. Second, part of the reason for our inability to predict future outcomes of present decisions is linked to the high interactivity of complex SESs. Such interactivity gives rise to the coevolution of different components of the SES (see Ch 1). Third, many of the objectives of policies arise from the perception of existing problems. Taking into account our inability to predict future outcomes of present policies we can understand how, even when such policies can solve the problem for which then were created, they give rise to new ones.

Box 3: Environment

It is now quite clear that human activities affect in multiple ways our natural environment. Although the scale of human activities started to increase significantly since the industrial revolution their potential impact on the environment did not raise any objections until after the second world war. By that time the impact of human activities was about to become of the same scale as that of phenomena. No prediction that this impact would have reached this point was made in advance. Until quite recently economists dismissed the possibility that the exhaustion of natural resources and the increasing pollution generated by human activities could substantially harm our natural environment and lead to a serious crisis if not to a catastrophic collapse (Georgescu Roegen, 1971; Daly, 2007). The earliest cries of alarm were in fact raised by naturalists (e.g. Commoner 1971) and by studies and reports (e.g. Club of Rome, 1972). Although such initial forecasts were sometimes exaggerated there is now a growing consensus that we have to change the way we produce and interact with the natural environment. However, when it comes to decide what strategies to adopt to make our development sustainable opinions still diverge considerably.

We now face both a cognitive barrier, constituted by our limited ability to predict the outcome of different decisions about present and future human activities, and a political barrier constituted by the opposition of groups in both developed and developing countries about who should pay or invest to reduce environmental impact. Thus, LDCs maintain that to reduce environmental impact is the task of developed countries (DCs) since they created the technologies that pollute our environment. Even in DCs there is no consensus about the timing an path to be followed to reduce environmental impact and make our SESs more sustainable. The transition towards more sustainable types of production is likely to be a combination of major innovations, most of which are going to harmthe firms and the workers in industries linked to past and polluting sources of energy and materials. This is a clear example of Schumpeterian creative destruction in which opportunities will be created for new technologies and industries while reductions in size and employment will occur for older industries. The opposition coming from the representatives of the oil and coal industries to the implementation of strategies aimed at reducing environmental impact (see Paris protocol) is an example of how vested interests based on incumbent and polluting industries oppose changes aimed at making our SESs more sustainable.

Adaptation to the natural environment is required at a world level, with different strategies used for countries at different levels of economic development. For example, countries that are suppliers of raw materials or of energy inputs will need to change their development strategies. DCs will need to develop new methods of production and styles of consumption that make our SESs sustainable.

While the problem of the environment shares with most other types of decision making the two barriers to adaptation, in this case the world dimension and the longer time scale magnify the impact of such barriers.

3.5.3) Decision making

All our decisions regarding adaptation are based on a limited knowledge and involve uncertainty, often of the radical type. We perceive past problems in a partial way, without a full understanding of all the factors that can have contributed to them and that keep affecting them. Essentially we neglect the systemic nature of our SESs and focus separately on one or few factors neglecting their interactions. As a result of this limited knowledge we end up at best solving past problems and creating new ones. Furthermore, we keep applying to some problems the same policies based on the way they were observed initially while such problems are undergoing important transformations (here see transformations vs transitions in Ch 2). A simple example of this can be given by the changing objective of health care systems. When they were created their mission consisted of supplying basic health care to everyone. Recently their objective has shifted from supplying basic health care to everyone to improving the quality of life by using a series of new but increasingly expensive medical technologies. Combined with an aging population this leads to an extremely fast and economically unsustainable rise in medical expenditures.

Thus, in general our inability to predict the outcomes of our initial adaptive decisions combined with the changing nature of the problems we intend to solve imply that, even when we succeed in solving past problems, we end up creating new ones. We could express this situation by saying that the solution to a past problem based on an incomplete knowledge generally leads to the emergence in the SES of contradictions which in turn will demand more, although always incomplete, solutions. In turn, the new solutions will at best solve the new contradictions and lead later on to further ones. Thus, no final state of history in which all problems have been solved and the SES is in a sort of Nash equilibrium where there are no tensions or desires to change can exist. On the contrary, our SESs are in persistent dynamical condition determined by a succession of different states.

4) Adaptive behaviour vs optimizing rationality

Generally our knowledge is so limited that it is impossible to use optimizing rationality. However, there are cases in which adaptation and optimization coincide. For example, if we had to make a choice which is very simple and in a constant environment, such as the choice of a product under the constraint of financial resources, we could say that our best adaptation strategy is the optimum. This is not possible in general since our choice problems are so complex that not only calculate the optimum but even to conceive it is impossible. Let us imagine a choice problem in which a person or a group needs to make a choice amongst some possible alternatives. If the person has a clearly established set of preferences and a given set of resources the solution is: the choice that maximizes utility, or satisfaction, within the existing resource constraint. The choice made in this way is the best adaptation strategy.

The possibility to find the above mentioned optimum depends on a number of assumptions which are rarely satisfied. Fist, the preference systems of different individuals have to independent (See Georgescu Roegen 1971). Second, even if the calculation is in principle possible the cost of computation could be extremely high or infinite (Simon 1969,1981; Beinhocker, 2007).Third, the calculation could be in principle impossible if we lacked the knowledge telling us what factors are likely to affect the outcome of our choice problem (here see qualitative change, discontinuities, radical uncertainty, discrete choices.

We can analyze possibility of describing economic behaviour as rationally optimizing behaviour by making reference to Friedman's metaphor. According to Friedman (Hodgson, 1998) although firms do not attempt to maximize profits, it is as if they were doing so because the firms that get closest to the optimum survive while those that remain further away from it go bankrupt. This implies that firms have at least some knowledge, however imperfect. Then firms that have the best knowledge base (KB), the one that most closely approximates the KB required to optimize, survive while the other ones go bankrupt. If we were to admit that firms had zero knowledge and that their behaviour differed in a purely stochastic way, we could still state that the firms whose performance most closely approximates the optimum would survive while the other ones with further from the optimum performance would go bankrupt. In this case firm performance would be determined purely by luck and no advice could be given to firms on how to improve their performance, quite a damning indictment for an economic theory. Thus, Friedman's metaphor needs to be reduced to differences in firms' KB so that firms having the closest to the optimum will survive while the other ones go bankrupt. Or, in other words, to attain optimum performance a firm will need an optimum knowledge base. In this context, it we accept that firms cannot have such an optimum knowledge base, Friedman's metaphor implies that getting as close as possible to the optimum is likely to require a non negligible amount of luck. Presumably a policy prescription recommending firms to be lucky would not be received very favourably by entrepreneurs and managers. The problem then turns to the nature of firm knowledge and to how it can be improved. In a simplified neoclassical view this knowledge would consist of an optimizing algorithm which, if fed the right information, can easily and costlessly calculate the optimum behaviour.

If such algorithm were costless and easily available to all firms then all of them would use it and their performance would be identical. An even casual observation of firm behaviour reveals that (i) no such algorithm is easily and costlessly available, (ii) when optimizing algorithms are available they are designed for specialized purposes and can only deal with very simplified and static environments, (iii) in general the amount of information required is not available, (iv) even when such information were available the computational costs could be unbearably high, (v) even more important, the conception of any optimizing algorithm needs to be based on a solid knowledge of the underlying SES. As it has been repeatedly pointed out so far, such knowledge is in general absent, particularly so in periods of radical and discontinuous change. Then, although we can identify some simplified and static environments in which it is possible to conceive and use an optimizing algorithm this is not possible in general.

A situation in which only highly incomplete knowledge would be available is the beginning of a transition (Geels, 2002). The introduction of a new economic species ES1 is dominated by entrepreneurial knowledge, that is, by knowledge which is sufficiently articulated to allow the formulation of broadly defined objectives but not to predict with any accuracy the future evolution of the SES, and in particular the structure of the subsystem constructed around the new ES1. Sometimes a choice has to be made amongst a set of discrete options, such as the multiplicity of designs existing at the beginning of technology life cycle (TLC) (Abernathy, Utterback, 1975; Nelson, Winter, 1977; Dosi, 1982). At this stage the knowledge present in the community related to the new ES1 is insufficient to conceive any model which could the basis of an optimizing algorithm. The development of the new ES1 and of its complementary institutions is guided by heuristics. Furthermore, the development of the subsystem built around the new ES1 is highly path dependent with decisions made at this stage affecting the subsequent development of all the subsystems. Often, the initial multiplicity of designs is followed by the convergence on a dominant design (Abernathy, Utterback, 1975; Nelson, Winter, 1977, Dosi, 1982).This does not end the differentiation of the ES1, but realizes it by combining in a modular way the components of the design (Explain better). As the technology of the new ES1 matures the knowledge present in the corresponding community becomes much more detailed, even if only within the existing regime/design/ paradigm. This knowledge is not necessarily scientific, in the sense of being deductively derivable from scientific theories, but, as compared to the knowledge present in the initial stages, it has an enhanced capability to explain, improve and make limited predictions about the evolution of the ES1 and of its subsystem. Within these limits the knowledge related to an ES1 can allow the construction of *locally limited* (see Ch 5) models, which can in principle be used to derive quasi optimizing algorithms (improve). Of course, in no case such algorithms are going to be costless or easy to use. Thus, although Friedman's metaphor would be completely irrelevant in the initial phases of the TLC, it could become increasingly meaningful as a broad approximation as the technology matures and become more predictable.

Even in these phases the advantage of having an optimizing algorithm would depend on its cost and on how it can help technologists to reduce the distance from the optimum, that is, from the frontier of the KB. Firms could not be classified as good or bad ones but on the basis of their distance from the optimum. Then the shorter their distance from the optimum, the better their knowledge base and the more advanced their performance would be. We can expect the cost of moving towards the optimum to increase more than linearly as the distance from the optimum falls. In this case a firm reducing quickly and by a limited amount its distance could increase its market share more than a firm attempting to go as close as possible to the frontier but more slowly and at a higher cost. To what extent Friedman's metaphor is an appropriate representation of firm behaviour is a mooted point.

In summary, we can say that the possibility for economic actors (firms, entrepreneurs) to make optimal choices regarding the evolution of technologies is in general very limited and only exists in situations which the ES1 technology, its community and its complementary institutions have become stable and locally well understood. Outside these situations knowledge can only develop by heuristics and learning by doing. Even within the mature phases of a TLC the cost and time of application of a potential optimizing algorithm are such that it the best performing firm(s) is not necessarily the one that gets closest to the optimum. However, although quasi optimizing algorithms can be and are used in economics, in the physical sciences and in technology, they are highly specialized and only 'locally' applicable.

In a population of firms we can expect to find a distribution of firms having KBs at different distances from their frontier, thus having different levels of performance and of profitability. Even the concept of frontier cannot fully represent the distribution of competencies and capabilities of existing firms. There may be firms that are leading their sectors, thus apparently being very close to the frontier, and other firms which are exploring avenues for future that could lead them to become future leaders. Thus, the frontier is being constantly redefined and measuring the distance from it can be problematic. In summary, Friedman's metaphor not only would be largely inapplicable to the emergence of new ES1s and of important transitions but would be very problematic even in a more stable situation in the maturing phase of a new ES1 and of the corresponding subsystem configuration

Thus, optimizing rationality can be an approximate representation of the behaviour of economic actors in a limited number of cases, although such cases may tend to occur with very high frequency, but far from transitions. In these cases the balance between the benefits and costs of using an optimizing algorithm could even be positive.

Summary.

In this chapter we defined the concept of adaptive behaviour focusing in particular on human beings and human communities. To this extent we distinguished clearly between adaptation *to* a given EE, which we called ADTO, and adaptation *of* a given EE, which we called ADOF, and maintained that the latter type of adaptation, while not completely absent in other biological species, is relatively much more important for human beings and human communities than for other biological species. The concept of adaptation was defined based on a systems approach.

While adaptation is in principle a general form of socioeconomic behaviour its application to both theory and policy is not necessarily easy. If it were all SESs would adapt to the same change in the EE in the same way. Here we analyze the problem of adaptation in terms of its objectives and barriers. In any SES the path followed by adaptation depends on the present structure of the SES and in particular on its institutions and social groups. Only a part of these, which differs for every SES, changes in response to a given modification of EE. Barriers to adaptation can be either cognitive or political. The former depend on our inability to predict the future evolution of our SESs, especially for what concerns qualitative types of change. The latter depend on the compatibility of existing institutions and power structures with the changes required for adaptation.

All types of adaptation, both ADTO and ADOF, occur at finite speeds. A change in the EE induces an adaptive response which occurs in a finite time. The emergence of a new economic species defines an attractor towards which the SES moves at a finite speed. The attractor so defined does not remain constant but changes in the course of time according to a technology life cycle (TLC). The SES could only reach a state of equilibrium if the attractor stopped changing, if the state of the SES caught up with it and if no new change in EE occurred. This combination of conditions is almost impossible to realize in an innovative SES. In a more likely scenario the emergence of a new economic species ES1 gives rise to a technology life cycle going through different phases characterized by different types and levels of uncertainty. Such an SES can undergo transitions to a qualitatively different SES or go through steady states in which the relevant state variables change gradually and quantitatively. A state of equilibrium, in which there are inducements to change, cannot exist in an innovative SES.

In a SES decision making is generally based on an incomplete or sometimes highly incomplete knowledge. No one can predict accurately the future evolution of important transitions, technological or of other types. Decision making it typically based on a selected subset of the variables or of the subsystems of given SES. As a consequence the solutions we develop for the problems we perceive can at best be expected to solve a part of the problem but are likely to give rise to other problems or contradictions in the future.

The possibility that adaptive behaviour can approximate optimizing rationality depends on the extent and type of uncertainty involved. In the initial phases of a discontinuous transition we can expect radical uncertainty to prevent any use of optimizing rationality. This would be particularly true when a choice has to be made amongst discrete alternatives each of which is very poorly known. On the other hand, in a situation in which the main components of the subsystem are relatively well known and only incremental innovations occur in the course of time it is possible for methods of decision making to approximate optimizing rationality.

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APPENDIX

Economic species (ES1): an economic species is here defined as a manmade artefact, which can be a physical product or a service, possessing an internal structure and supplying some services to its users. Economic species are qualitatively different from one another. Examples could be product technologies, such as cars, portable telephones and computers. The definition can be extended to machine tools, process technologies and pure services. Any type of output, whether material or immaterial, is expected to produce services. Typically economic species go through a technology lifecycle (TLC) beginning with a transition, involving qualitative change and radical uncertainty, and continue with a long series of incremental and more predictable innovations.

Efficiency: Efficiency is here defined as measuring the ratio of outputs to inputs for a given productive process at constant output type. Efficiency increases when smaller quantities of inputs are used to produce one unit of output at constant output type. In this sense efficiency measures only quantitative changes in a production process.

Creativity: Creativity gives rise to the emergence of new types of output qualitatively different from anything existing before. Thus, efficiency and creativity are two different concepts, but they are related since growing productive efficiency is required to provide the resources required for creativity. Continued economic development requires the creation of new economic species through the joint effect of efficiency and creativity.