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The Economics of Nature: Constrained Dynamic Optimization and Efficient Decentralized Decision Making in Nature

Jong Soue You

Department of Economics, Algoma University, Sault Ste. Marie, ON, Canada
Email: jong.you@utoronto.ca

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Abstract

The paper suggests that the study of economics as being practised in the economics profession today is needlessly human centered. Evidence is presented that the driving force behind activities of all living organisms including humans is economic in nature. Their behaviors are driven by the objective of constrained dynamic optimization, i.e., that they behave rationally. Further, whenever large-scale groups are formed such as colonies of ants and bees, and trees of the forest, they resort to decentralized decision making to obtain efficiency. The evidence for this proposition is rooted in a wide range of observations on the behaviors of many plants and animals and indeed in how their genome is organized and functions. Recent research suggests that the origin of life itself had the underlying motive that was economic in nature, i.e., that life was not a chance occurrence but an inevitable outcome of energy-dissipation-driven organization of the matters behaving so as to maximize the economic efficiency along the evolutionary path of increasing entropy production. Further, observations on a wide range of natural phenomena, including straight-line path of sunlight, symmetry of snowflakes and crystals, lead us to believe that it is not just living organisms that behave rationally but inorganic matters as well rationally in the sense that they behave with the objective of constrained dynamic optimization that produces efficient outcome.

Keywords

Dynamic Optimization, Decentralized Decision Making, Economic Efficiency, Economic Natural Selection

1. Introduction

Marshall (1890) defined economics as “a study of man in the ordinary business of life. It enquires how he gets his income and how he uses it. Thus, it is on the one side, the study of wealth and on the other and more important side, a part of the study of man". Robbins (1932) defined economics more broadly as "a science which studies human behaviour as a relationship between ends and scarce means which have alternative uses". Robbins' definition of economics is perhaps the most commonly accepted modern definition of the subject.

Built on the foundation of Robbins' definition, economists have pushed the frontiers of economic analysis to the farthest limits and have come to formulate the theory of constrained dynamic optimization, that is, dynamic maximization of benefits under cost constraints or dynamic minimization of costs under budget constraints, as a fundamental cornerstone of economic analysis (Dixit, 1990; Kamien & Schwartz, 2012). Economic analysis by economists, however, has so far been confined to the realm of human behaviors, true to the spirit of Alfred Marshall and Lionel Robbins.

Recently Dawkins (2009) observing the evolution and behaviours of species, has advanced a theory that explains optimum height of a tree. According to Dawkins, the optimum height of a tree is determined by the equality of the marginal benefit and marginal cost of additional height. The marginal benefit of additional height is represented by the additional carbohydrate energy photosynthesized from the additional sun light the additional height makes possible. The marginal cost of additional height is the additional amount of carbohydrate energy needed for the tree to grow the additional height. After all, if this weren't the case, what is there to stop the tree from growing taller and taller without limit? Why do some trees grow tall and some not as tall? It must be because different trees face different sets of environmental constraints. Every tree must solve a set of constrained dynamic optimization problems, i.e., a set of differential equations subject to a set of environmental constraints to determine the optimum height and, in fact, in all decision making. We know that this is certainly the case for decision making by humans. All decision making by human beings is economic decision making and is assumed to be rational. It appears that it can also be argued that all decision making by non-human species is also rational economic decision making rational in the sense of constrained dynamic optimization.

Is the rational decision making by the humans and non-human species a result of conscious calculation of marginal benefits and marginal costs and of conscious constrained dynamic optimization? Certainly not. Decision making by the organic species in general is a result of unconscious actions driven by instincts and perhaps more fundamentally by hidden natural forces. And yet, it manifests itself as a rational behavior. What are then the natural forces that drive the rational behaviors of the human and non-human species? This is the subject of inquiry in this paper.

Further, we know that the decentralized decision making based on constrained dynamic optimization leads to an efficient resource allocation in the human society. Evidence seems to suggest that this is the case in the non-human organic worlds as well. The colonies of ants and bees provide excellent examples of constrained dynamic optimization and efficient decentralized decision making as are the flocks of birds and schools of fish in the non-human organic world as will be seen below.

If the rational and efficient decision making by the organic species is driven by some unknown natural forces, what is there to stop the same line of reasoning from being extended to the realm of inorganic world? Wouldn't it be natural to conjecture that the same fundamental natural forces must be driving the behaviours of the inorganic matters as well? In fact, it does seem reasonable to assume that the similar constrained dynamic optimization problems are encountered and must be solved by the matters in the inorganic world to the ones being faced by the organic species. For example, physicists believe that sun light travels in a straight line because the straight line represents the least cost optimum trajectory in terms of time elapsed under the constraints of the four fundamental forces of nature (gravitational, electromagnetic, strong nuclear and weak nuclear) (Greene, 2004).[1] Another example: why do snowflakes have symmetrical shape? Presumably it is for the similar reason that the symmetry is the least cost structure representing the optimal solution to a set of constrained dynamic optimization problems at hand.[2] What about crystals? The list goes on and on.[3] It is quite possible that the constrained dynamic optimization is universal phenomenon spanning the organic as well as inorganic world and that all matters must constantly solve constrained dynamic optimization problems of various kinds as they travel along their evolutionary paths of increasing entropy.

What significance does this have for human welfare? A great deal it seems. If understanding of the way optimum height of a tree is determined has direct relevance to human welfare and it does, then so should understanding of optimum evolutionary trajectories of inorganic matters. That the economic methodology of constrained dynamic optimization has virtually universal applicability should not be surprising because, after all, unfolding of the universe can be said to be governed essentially by the economic laws of thermodynamics, which again are governed by the four fundamental forces of nature. In what follows, I present the situations in both the organic and inorganic worlds, understanding of which requires the application of the law of economic efficiency.

The plan of the paper is as follows. Section II presents a discussion of constrained dynamic optimization and efficient decentralized decision making in the organic world. This is followed by a discussion of constrained dynamic op-

[1]Danish astronomer Ole Christensen Romer, who is credited for the first measurement of the speed of light in 1676, believed that the straight-line path of the sun light was the path of minimum time.

[2]According to Miriam Rossi, a professor of chemistry at Vassar College, "snowflakes are symmetrical because they reflect the internal order of the water molecules as they arrange themselves in the solid state (the process of cry-stallization)…During this process, the molecules align themselves to *maximize* the attractive forces and *minimize* the repulsive ones. As a result, the water molecules arrange themselves in predetermined spaces in a specific arrangement and maintain symmetry (Rossi, Glusker, & Lewis, 1994)."

[3]Joseph-Louis Lagrange believed that most theories in physics, if not all, can be formulated in terms of *minimization or maximization* of a suitable quantity (Clerke, 1911).

timization and efficient decentralized decision making in the inorganic world in Section III. Section IV presents a plausible economic motivation behind the origin of life. Section V concludes the paper.

2. Constrained Dynamic Optimization and Efficient Decentralized Decision Making in the Organic World

Economic efficiency is represented by a solution to a constrained dynamic optimization problem. A remarkable truth is that, when individual members of a community achieve efficiency through constrained dynamic optimization under a set of given resource and environmental constraints, the community as a whole achieves efficiency and this is done without a central control. A good example is the market mechanism in the human society. For simplicity, we focus on a big picture where the problems of market failure are ignored. Other examples in non-human worlds abound.

2.1. Efficient Decentralized Decision Making in the Colonies of Bees and Ants

Biologists and ecologists have long observed that the colonies of bees (Tautz, 2009)[4] and ants (Gordon, 2016)[5] are organized on the basis of decentralized decision making by individual members of the colonies responding efficiently to their changing environmental constraints without any central control or coordination. Individual members of the bee or ant colonies solve the constrained dynamic optimization problems they are faced with as they go about their daily living and as they interact with one another under their environmental constraints. The interactions represent the constrained dynamic optimal responses and they produce an efficient outcome without central control or coordination.[6]

2.2. Efficient Decentralized Decision Making in the World of Genome

It is now widely understood that the world of genome in organic life including

[4]In the words of Tautz (2009), "We are surprised to learn that no single bee, from queen through drone to sterile worker, has the oversight or control over the colony. Instead, through a network of integrated control systems and feedbacks, and communication between individuals, the colony thrives at consensus decisions from the bottom up through a type of 'swarm intelligence'."

[5]Gordon (2016) has this to say about the ant colonies: "An ant colony consists of many sterile female workers and one or more reproductive females. Even though these reproductives are called 'queens', they have no power or authority. They just lay the eggs. Regulation without central control uses simple interactions…Ants interact by means of smell when one ant smells another with its antennae, it can assess whether the other ant is a nest mate, and what task the other ant has been doing. The pattern of interactions produces the behaviour of the whole system…An ant uses its recent experience of antennal interactions to decide what to do next.'"

[6]Decentralized decision making in the present context is a concept fundamentally different in its nature from the decision making tools or techniques proposed in the economics of decision making literature such as analytical hierarchical process (AHP) studied by Sharma (2018). Decentralized decision making considered here involves no central control or coordination. AHP, for example, is a conscious decision making technique which requires a direct involvement of the decision maker.

that of humans is a highly efficient decentralized system of signalling and responses without a central control (Ridley, 1999), analogous to the efficiently functioning market mechanism in the human society. The brain does not control the body functions but the body including the brain functions as an integral system of signals and responses without a central control. This is a highly efficient biological system with decentralized signalling and responses, a product of natural selection (Darwin, 1859). Efficient economic system is a decentralized system of signals and incentives. It is an evolutionary outcome of natural selection. Natural selection ensures an efficient outcome.

Any biological system designed to be controlled by a central command would not have the kind of flexibility and adaptability required for survival in the constantly and often unpredictably changing environment.

2.3. Other Collective Optimizing Behaviors in the World of Organic Species

We also find that birds fly in formation, fish swim in schools and insects swarm. These are all examples of collective optimizing behavior. The collective behaviors of these organic species reflect the optimizing behaviors of the individual members of the group, which represent the solutions to the constrained dynamic optimization problems the individual members are faced with under their respective environmental constraints. It is well known that migrating birds fly in formation to conserve energy by taking advantage of the up-wash vortex fields created by the wings of the birds in front. Another hypothesized reason for their flying in formation is to facilitate orientation and communication among the birds. Fish swim in schools because schooling protects them from predators making it difficult for a predator to zero in on one single fish, encourages reproduction and apparently makes it easier to find food. Schooling also conserves energy, as each fish drafts in the wake of the fish ahead of him. This makes it easier for fish to swim long distances without exhaustion. These are the further examples of constrained dynamic optimizing behaviors and efficient decentralized decision making in the world of organic species.

The discussions presented above lead us to believe that every act of an organic being is a result of some type of constrained dynamic optimization. We are also led to believe that the optimizing behaviors of the individual members of a group lead to an efficient outcome for the group as a whole without a central control. The optimizing process and the resulting efficient outcome are guided by an invisible hand. What is the nature of this invisible hand? The information driving the whole system is contained in the genome, which is the evolutionary outcome of natural selection. The evolutionary process of natural selection is a constrained dynamic optimizing process and also an efficient process. In this sense it can be said that the law of natural selection is a law of economically efficient evolutionary process.

Focusing on the human market economy in particular, several economists

(Alchian, 1950; Friedman, 1953) have invoked the hypothesis of natural selection to justify the assumption that economic agents behave rationally and their behaviors lead to efficient resource allocation. Use of the rationality hypothesis in economic analysis can be justified although not everyone behaves rationally and not always since, as Blume & Easley (1993) correctly point out, "the market selects for those whose behavior is most nearly optimal." Natural selection ensures that "ultimately the market is dominated by seemingly rational individuals and prices converge to their rational-expectations equilibrium values." For the purposes of this paper, however, it should be made clear that the economic law of natural selection applies broadly not only to the human market economy but to the economies of all species.

The observations above strongly suggest that the constrained dynamic optimization behaviours by the individual members of the societies of organic species and the resulting efficient outcome of decentralized decision making may be only a reflection of more fundamental forces of nature working in the background. It naturally follows then that the fundamental natural forces that are responsible for driving the dynamic optimizing behaviors and resulting efficient outcomes in the organic world must be the same ones that are motivating and driving the behaviors of the inorganic matters as well.

3. Constrained Dynamic Optimization and Efficient Decentralized Decision Making in the Inorganic World

We in fact find many examples of what can only be described as the constrained dynamic optimization and efficient decentralized decision making by the matters in the inorganic world. One obvious example is "internet". Internet provides an excellent example of efficient decentralized decision making in the inorganic world of machines. No single entity, academic, corporate, governmental, or non-profit administers the internet. It exists and functions as a result of the fact that hundreds of thousands of separate operators of computers and computer networks independently decided to use common data transfer protocols to exchange communications and information with other computers, which in turn exchange communications and information with still other computers. There is no centralized storage location, control point, or communications channel for the internet. The computers or computer operators act like ants or bees or neurons in sending signals and responding to signals thereby contributing without knowing to the highly efficient decentralized system of decision making without a central control. Notice that the computer operators are living organisms but the computers are inorganic machines and that it is the inorganic machines that are driving the system of internet, not the computer operators.

As mentioned earlier, the traveling path of sunlight and the symmetric shapes of snowflakes and crystals may be only a few of the numerous examples of efficient solutions to the constrained dynamic optimization problems faced by inorganic matters, which are economic in nature. What is common in all of these natural phenomena is the working of the law of economic efficiency driven by the fundamental forces of nature (i.e., gravitational, electromagnetic, strong and weak nuclear forces). It is not just organic species but inorganic matters as well that must behave optimally. These observations lead us to suspect that the law of economic efficiency underlies the unfolding of the universe itself in a fundamental way.

4. Economic Motivation behind the Origin of Life

Considering the fact that the motive of economic efficiency underlies the constrained dynamic optimizing behaviors of all organic life forms and even the movements of all inorganic matters, it would not be surprising if it was the case that the fundamental motivation for the origin of life itself turned out to be also economic. Recent research seems to suggest precisely that. Recently reported research findings in biophysics strongly suggest that the origin of life on earth was an inevitable outcome of the tendency of increasing entropy or the second law of thermodynamics (Michaelian, 2011; England, 2013). According to this view, the principle driving the origin of life is energy-dissipation-driven adaptation of matter.[7] In this view, life is a result of maximizing entropy production through a maximum dissipation of sun light energy efficiently transforming it into heat. In other words, the molecules are driven by the fundamental forces of nature to solve the constrained dynamic optimization problems they are faced with. The result is an efficient maximization of entropy production which reflects what may be termed "the economic law of evolution".

A similar view is advanced by England. According to England, "when a group of atoms is driven by an external source of energy (like the sun or chemical fuel) and surrounded by a heat bath (like the ocean or atmosphere), it will often gradually restructure itself in order to dissipate increasingly more energy. This could mean that under certain conditions, matter inexorably acquires the key physical attribute associated with life. From the standpoint of physics, there is one essential difference between living things and inanimate clumps of carbon atoms: The former tend to be much better at capturing energy from their environment and dissipating that energy as heat. A plant, for example, is much better at capturing and routing solar energy through itself than an unstructured heap of carbon atoms. Thus, under certain conditions, matter will spontaneously

[7]To borrow Michaelian's words: "Understanding the thermodynamic function of life may shed light on its origin. Life, as are all irreversible processes, is contingent on entropy production. Entropy production is a measure of the rate of the tendency of Nature to explore available microstates. The most important irreversible process generating entropy in the biosphere and, thus, facilitating this exploration, is the absorption and transformation of sunlight into heat. Here we hypothesize that life began, and persists today, as a catalyst for the absorption and dissipation of sunlight on the surface of Archean seas…RNA and DNA are the most efficient of all known molecules for absorbing the intense ultraviolet light that penetrated the dense early atmosphere and are remarkably rapid in transforming this light into heat in the presence of liquid water. From this perspective, the origin and evolution of life, inseparable from water and the water cycle, can be understood as resulting from the natural thermodynamic imperative of increasing the entropy production of the Earth in its interaction with its solar environment."

self-organize. This tendency could account for the internal order of living things and of many inanimate structures as well." England observes: "Snowflakes, sand dunes and turbulent vortices all have in common that they are strikingly patterned structures that emerge in many-particle systems driven by some dissipative process." "Self-replication, the process that drives the evolution of life on Earth, is one such mechanism by which a system might dissipate an increasing amount of energy over time. The best way of dissipating more energy for an organism is to make more copies of itself." observes England.

The underlying economic principle here is that the atoms are driven in such a way as to maximize dissipation of energy under the constraints of the fundamental forces of nature. This may be interpreted as a type of efficient solution to a constrained dynamic optimization problem. The origin of life was then not a low probability event that occurred coincidentally under a set of highly restrictive conditions. Rather it was an inevitable natural phenomenon driven by the economic principle of maximum energy dissipation under the given environmental constraints along the evolutionary path of increasing entropy (constrained dynamic optimization). This explanation is consistent with the fact that life on earth appeared rather quickly after the birth of the planet as soon as the earth crust got cool enough to hold liquid water around 3.6 billion years ago well before even oxygen was present in the earth atmosphere. If this is the case, it may be true that the universe is unfolding along the evolutionary path of efficient decentralized decision making by the matters obeying the fundamental laws of thermodynamics or the fundamental law of economic efficiency without a central control or with no one in charge.

5. Conclusion

In this paper, I suggest that the study of economics as has been and is currently being practised in the economics profession is needlessly human centered. Evidence seems to suggest that the driving force behind all activities of animals and plants and indeed all organisms in the organic world including humans is economic in nature. Their behaviours seem to be driven by the objective of dynamic optimization under the environmental constraints they are faced with, i.e., that they behave rationally. The evidence for this proposition is rooted in a wide range of observations on the behaviors of many plants and animals and indeed in how their genome is organized and functions. Recent research seems to suggest that the motive of economic efficiency underlies the origin of life itself as life can be viewed as the inevitable outcome of economically efficient energy-dissipation-driven organization of matters along the evolutionary path of increasing entropy production.

Further, evidence seems to suggest that it is not just living organisms that behave rationally but inorganic matters as well, rationally in the sense that they behave with the objective of constrained dynamic optimization that produces efficient outcome. The evidence for this proposition comes from observations on a wide range of natural phenomena including the path of sunlight, the symmetric structure of snowflakes and crystals, the formation of hurricanes and ocean currents, and the way the computer network known as "internet" works to bring about an efficient decentralized decision making mechanism.

It is striking that the motive of economic efficiency underlies the behaviours of all successful physical systems, both organic and inorganic, and that all successful systems, organic or inorganic, can be said to behave rationally, successful in the sense that they have been successful in surviving the rigorous natural selection process. It may not be an exaggeration then to suggest that the unfolding of the universe itself is guided by what is akin to Smith (1776)'s invisible hands, that is, efficiency through a decentralized system of signalling and responses.

On a more practical level, it is worth reminding ourselves that the economic behaviors of all entities, be they organic or inorganic, grounded on the optimizing incentives are so fundamental and so pervasive in nature that ignoring these fundamental natural forces in the design and implementation of economic or other policies are bound to fail, be it income maintenance (Friedman, 1953) or environmental protection (Guerin, 2003) policies, just to name a few.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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