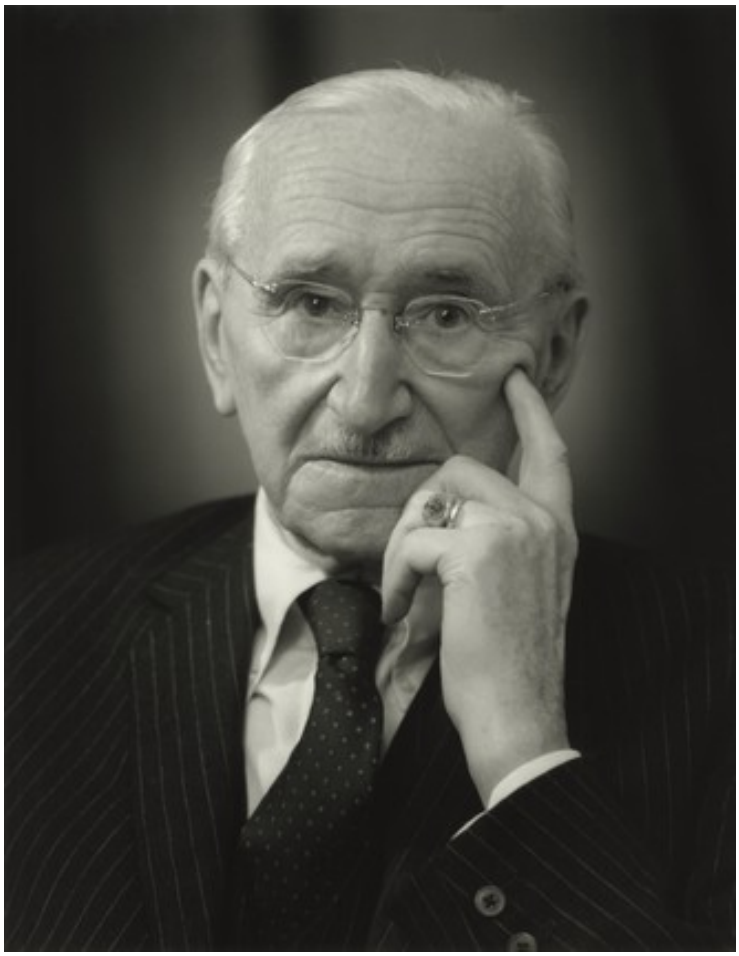
Hayekian Complexity

An Inquiry into the Hayekian Roots of Complexity Economics



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Introduction

When surveying the modern History of Economic Thought, the observer cannot avoid being struck by the dominance of a single scientific paradigm: reductionism. The roots of this doctrine's ascendancy date back to the scientific revolution of the 17th century. Sparked by the philosopher René Descartes, it was to prove a revolution which was to change mankind's place in the world beyond recognition. Foremost among the more modern adherents of this doctrine were those associated with the so-called "Vienna Circle" who, in the interwar period, undertook to formulate a universal scientific methodology capable of building future scientific inquiry upon the foundations of rationality, as opposed to superstition. Instrumental to this scientific methodology are assumptions of linearity, systematizing empirical phenomena so as to analyse them in an explicitly reductionist fashion, based upon the work of perhaps greatest scientist of the pre-modern scientific revolution, the great Isaac Newton. This, then constitutes one of the two bloodlines of thought treated in this paper.

Additionally, this work has as its goal the elucidation of the antireductionist counterstrike launched against this dominant doctrine and will focus primarily on the work of the economist and political philosopher Friedrich A. Hayek. Upon the whole, Hayek can be named as the most important exponent of the antireductionist faction of economists, developing views of economic agents, knowledge, and institutions—economic, cultural and political—which are not only likely to stand the test of time, but are also probably going to furnish coming generations of economists with a new framework upon which to base their future inquiries.

While Hayek focussed primarily upon the evolution of economic and legislative institutions, his theory extends in seamless fashion to other spheres of science and thought, as shall be demonstrated in this paper.

The less well-known facet of Friedrich Hayek's intellectual life alluded to above, in time, made him one of the earliest exponents of the then non-existent field of complexity economics.

We shall, ultimately, see a coherent alternative paradigm emerging, one capable of rivalling and in certain areas displacing the currently dominant doctrine of scientific reductionism with its assumption of linearity on the part of the systems to be observed in the empirical world.
While no one methodology can credibly promise the ultimate say in terms of true economic theory, the dominance of reductionist and positivistic thought has served not only scientific progress. As this paper will show, a more mixed approach to economic theorising may be adequate; and it was Friedrich A. Hayek, the Viennese émigré, who would be found by many to be responsible for pioneering many elements of what is by now known and established as complexity economics in the English-speaking world.

Reductionism

Friedrich A. Hayek, whose work constitutes the main focus of this paper, was a relative of the great philosopher Ludwig Wittgenstein. Though we have no evidence of any direct intellectual cross-fertilization between these two men, we are justified in purporting that they were instrumental in sparking radically countervailing trends in scientific thought and methodology.
Wittgenstein served—together with Ernst Mach and Bertrand Russell—to initiate a revolution in scientific methodology in general. As they saw it, their radically new doctrine was destined to clear away the unnecessary "metaphysical" ruminations of the Victorian-era and fulfil the promises proffered by the so-called Enlightenment, allowing scientists—economists among them—to approach their scientific challenges in hitherto unknown ways.
In order to arrive at a coherent picture of Hayek's contribution to the science of complexity, we must therefore first venture into an investigation its methodological nemesis.

During the early days of the 20th century, reductionism was conceived on the basis of an exciting new wave of scientific optimism, a wave of the future which seemed to promise the final stage of man's ascent away from ancient

dogma and render him capable of straddling nature by dint of his intellectual and scientific prowess (Ray, 2001, p. 243ff).

Reductionism may, for the purposes of this paper, be defined by a broad methodology operating by breaking the object under scientific analysis down into its smallest possible constituent part and isolating it, in order to conduct experiments with it, so as to gain knowledge of the universal principles governing its nature (Nagel, 1998, p. 1ff). This approach paid off handsomely in the area of Newtonian physics, before quantum physics was to revolutionise the discipline from within. In the context of economics, this approach would proceed by isolating the smallest possible unit of an economic system to the micro-level analysis (Mitchell, 2009, p. i). Having separated the phenomena under observation in this way, further valuable conclusions follow from reassembling the micro-elements into aggregated macro-elements, permitting of a different macroscopic level of analysis.

The first major and systematic thinker to espouse the reductionist view was René Descartes, whose adherents, as we shall see further below, take this starting point to its logical conclusion as it relates to scientific matters (Mitchell, 2009, p. i). Descartes' notion of scientific methodology is a perfect and canonical description of this particular approach to science, eagerly followed by Isaac Newton some years later. As Melanie Mitchell writes:

> "Reductionism has been the dominant approach to science since the 1600s. René Descartes, one of reductionisms earliest proponents, described his own scientific method thus: "to divide all the difficulties under examination into as many party as possible, and as many as were required to solve them in the best way" and "to conduct my thoughts in a given order, beginning with the simplest and most easily understood objects, and gradually ascending, as it were step by step, to the knowledge of the most complex."
> (Mitchell, 2009, p. i)

This view cascaded through the western academy, accelerated by the prestige afforded to it by the scientific revolution led by Newton (Westfall, 2001, p. 243ff)[1].

[1] Further below, we shall reencounter René Descartes in Friedrich Hayek's criticism of a specifically Cartesian notion social constructivism. It is noteworthy that, in treating the differences between reductionism and antireductionism, we notice coherent red lines emerging, setting against one another scientists and ideas often separated by centuries.

The primary modern progenitors of this modern stage of the scientific revolution were the aforementioned Ludwig Wittgenstein, Bertrand Russell, Ernst Mach and the members of the Vienna Circle, such as for example Moritz Schlick, Rudolf Carnap, Richard von Mises, and many others (Ray, 2001, p. 243ff). They derived lessons from modern advances in physics and the new Darwinian worldview which would, in time, put them at odds with a new antireductionist movement in opposition to them, led, among others, by a contemporary compatriot of the men mentioned above, Friedrich August von Hayek, as he was then still called.

The Doctrine

While the Western scientific community had before the paradigm shift described above been torn between the extremes of Hume and Kant and had therefore concluded with an eclectic set of methodologies serving the explanation of scientific phenomena, Wittgenstein's innovation would lead the scientific mainstream to consolidate in more or less one corner of the methodological spectrum (Wittgenstein, 2016). Wittgenstein's main work was preceded by the general battle between the philosophical notions of realism and idealism, manifesting themselves in different ways in the scientific community (Diamond, 1995, p. 513ff). While the realist faction among scientists sought to explain what they saw as an objective world external to the observing, subjective scientist, the idealists concluded that man could not arrive at a non-contradictory notion of the external world due to his sensory inputs inevitably accounting for all he knows. Faced with this contradiction, scientists down the ages had attempted to elucidate reality by means of conceptualising it by use of language in the form of propositions and applying logic to these in order to arrive at new knowledge. This view accorded to language the role of mediating tool between the various members of the scientific community, enabling them to comprehend one another's theses and thereby allowing them to promulgate. Wittgenstein, however, suggested that from the point of view of the scientific subject, in a fundamental sense, language constitutes reality instead of merely describing it (Scruton, 1994, p. 50ff). The scientist is therefore in a position of making "positive" statements concerning reality induced by his sensorial

equipment alone, without applying himself to aprioristic reasoning (Grayling, 1997, p. 38ff).
Thus, logical positivism (the methodological subcategory of reductionism) was born as a logically coherent way of incorporating pure empirical sense data as an equivalent to language in order to incrementally generate and later on corroborate scientific theses. In the word of Milton Friedman:

> "Positive economics is in principle independent of any particular ethical position or normative judgements. As Keynes says, it deals with "what is", not with "what ought to be." Its task is to provide a system of generalizations that can be used to make correct predictions about any change in circumstances. Its performance is to be judged by the precision, scope, and conformity with experience of the predictions it yields. In short, positive economics is, or can be, an "objective" science, in precisely the same sense as any of the physical sciences. Of course, the fact that economics deals with the interrelations of human beings, and that the investigator is himself part of the subject matter being investigated in a more intimate sense than in the physical sciences, raises special difficulties in achieving objectivity at the same time that it provides the social scientist with a class of data not available to the physical scientist. But neither one nor the other is, in my view, a fundamental distinction between the two groups of sciences."
>
> (Friedman, 2009, pp. 4-5)

In 1947, 6 years before Friedman was to lay down his own positivistic principles, Paul Samuelson mentioned in his "Foundations of Economics Analysis" that the marketplace lends itself to empirical analysis exclusively, underlining the wholly empirical nature of the positivistic methodology followed by the economic mainstream (Samuelson, 1947).
Based upon these methodological foundations, the reductionist dominance of economic theory was established. Both the Monetarists of the Chicago School of Economics as well as the post-Second World War Keynesians adopted the positivistic methodology, which proved a necessary precursor to a wholly reductionist conception of economics.

The Doctrine's Impact

Upon the whole, we can trace back the origin of the current economic mainstream to the years succeeding the high-tide of Logical Positivism. Both the Chicago School of Economics—represented by Frank Knight, Henry Simons, Jacob Viner, Milton Friedman and George Stigler—and the then ascendant Keynesians—represented by Paul Samuelson, Abba Lerner, and, in our own day, Paul Krugman—adopted these methodological presuppositions in their entirety to replace the more mixed selection of approaches championed by no lesser economists than John Maynard Keynes, Irving Fisher, Ludwig von Mises and the main focus of this paper, Friedrich A. Hayek.

The consequences will lead us directly to the main scientific controversy treated in this paper: the conflict between the reductionist "Newtonisation" of economics and the antireductionist approach of complexity economics, pioneered by F. A. Hayek. The reason for this conflict is conferred by the simple fact that a scientific philosophy based upon the doctrine of Logical Positivism cannot, **by its very nature**, account for the complexity exhibited by the external world which the scientist, by the nature of his profession, is obliged to explain and elucidate. Due to the fact that the positivistic methodology necessitates a "fusion" between the sensorial data empirically gathered and the actual metaphysical reality of the scientific object, it is by its very constitution blind to more complex phenomena due to the fact that the generally accepted principle of Occam's Razor precludes the use of scientific models which are more complicated than necessary to adequately describe economic phenomena. Thus, additionally endowed with a verificationist philosophy of science, economists have frequently opted for simplicity over seemingly unnecessary complexity. From the 1930s on, this philosophy was subjected to heavy criticism by the philosopher Sir Karl Popper (Popper, 2014). In his view, the verificationist doctrine was flawed in that it failed to satisfactorily treat the so-called problem of induction. The alternative, according to Popper, was to make daring conjectures and open them up to scientific falsification, as opposed to the verificationist standpoint, which was based upon the gradual and unremitting increase in positivistic information

gathered (Popper, 2002, p. 43ff). While both have some overlap and sometimes evaluate various phenomena equivalently, Popper's philosophy leaves the economist with the opportunity to write-off positivistic models which don't predict economic phenomena well and to replace them with other, more complex models which might violate a simplistic notion of Occam's Razor, but provide the economist with a more predictive analytical tool.
We are therefore justified in stating that the adoption of a positivistic scientific methodology has lead and must by its very nature lead to a substantial philosophical bias in favour of a broader, reductionist framework of scientific thought. As a consequence, economic phenomena are, for the most part, a priori believed to be of a systemically linear nature, as opposed to a complex notion of non-linearity and antireductionism. We may furthermore state that logical positivism has made its adherents the staunchest supporters of an analysis of economic phenomena as linear systems in perhaps the entire scientific community. Whereas physics, during the early 1900s, eagerly cast away the old Newtonian worldview in favour of quantum physics and Einstein's theories of general and special relativity, the economic community would take a decided turn toward the pre-Einsteinian, Newtonian worldview.
In the following, I shall further set the stage for the entry of Friedrich A. Hayek and the antireductionist answer to the logical positivists by listing the core premises of reductionist economics, only to compare them to the soon-to-be-treated alternative.

Reductionist Economic Theory

The hallmark of "reductionist" economics lies in what one could call a "linearisation" of scientific research and analysis. The causal relations the economist wishes to establish are therefore described and analysed according to an expressly linear notion of cause-and-effect, as one would analyse a simple linear relationship between, for instance, a stone descending to the ground according to the laws of gravity. In essence, linear system exhibits a strict proportionality between the inputs into a systems and the resulting outputs. It therefore seems fitting for the reductionists to disassemble a system

into its constituent parts, seeing as their spatial reallocation must necessarily proceed according to principles of strict proportionality. Given proportionality, a truly linear system becomes analysable in a wholly new way—which was the exact innovation bequeathed to mankind by the early scientific revolution of Descartes and Newton.

As a consequence of this, the decisions made by an economic agent are treated in an equivalent fashion by the economist, due to the fact that his positivistic methodology strongly favours the simplicity of linear systems as compared to the complexity of non-linear systems. Occam's Razor requires the inquiring scientist to shed his hypothesis of any deadweight in describing phenomena of the external world. Therefore, if the economist adhering to the tenets of logical positivism finds himself confronted with a certain dataset, his methodological framework will immediately bias his inquiry toward a linear and reductionist approach of attaining a hypothesis, due to the fact that models built upon these premises afford the economist greater clarity and simplicity as compared to having to concede a lack of knowledge and predictive powers, as scientists treating complex phenomena often are forced to do.

As a consequence, the simplicity inherent in a Newtonian view of economic phenomena becomes seductive, all the more so due to the cultural prestige commonly accorded to physicists. The empirically-minded economists since Hayek's day have, due not only to these factors, abandoned the humbler, methodologically mixed approaches proffered by other schools of economic thought in favour of a methodology which allowed them to conclude with hypotheses which were, on the surface, empirically justified, but, as was dramatically demonstrated by the financial crisis of 2008 and 2009, failed in terms of their actual predictive power when their scientific precision was needed most.

The Application of Reductionism

The core and unifying strand which unites otherwise disparate factions of economic thought under the banner of reductionism is the common nature according to which economic systems are viewed by them. As has been suggested above, reductionist economics proceeds by reducing the scope of economic analysis to the smallest possible unit, only to re-aggregate these units

in order to gain a more holistic, global picture. In modern reductionist economics, the smallest feasible unit of economic inquiry is the individual economic agent who is widely accepted to be describable as "homo oeconomicus"—the economizing man—and is treated by microeconomic analysis. If, in the case of a marketplace, many such men aggregate together to form a large number of economic agents, macroeconomic methods take the helm of economic analysis. Homo oeconomicus is, by assumption, endowed with a collection of attributes which make his behaviour analysable by mathematical and econometric methods.

Naturally, homo oeconomicus is but a model man and is not by the reductionists meant to resemble the average person. However, the models assumptions matter, seeing as they are not of an empirical nature, but only use the empirical data which is fed into the model upon having arrived at these a priori notion of homo oeconomicus. When later reviewing the entirely empirical models of complexity economics, this difference shall grow in importance.

Among the attributes asserted are:

Rationality

According to two of the champions of reductionist thought, John von Neumann and Oskar Morgenstern, the individual is modelled according to various behavioural axioms regarding his preferences in order to maximise his utility (Von Neumann & Morgenstern, 1944). In this case, homo oeconomicus is assumed to display preferences which make his market behaviour analysable:

1) Transitivity
2) Completeness
3) Continuity

Omitting Von Neumann and Morgenstern's further enquiries, we can state that their version of homo oeconomicus endows man with maximal degree of rationality with regards to his process of utility maximisation, which indeed he needs if he is meant to solve the entirely rationalist problems of game theory, a field which John von Neumann and Oscar Morgenstern pioneered.

Information and Knowledge

In a similar vein, homo oeconomicus is, for the purposes of scientific modelling, assumed to possess complete information, leading him, in theory, to being able to coordinate his market decisions adequately. In the commonly cited "Arrow-Debreu" economy, individual agents are atomistic price-takers who rationally react to the price signals given to them by the market laws of supply and demand (Arrow & Debreu, 1954). Applying the rationality with which he was endowed, homo oeconomicus allocates his given resources according to given constraints in order to maximize his utility according to his preferences.

Equilibrium

Paul Samuelson stated the most commonly held reductionist view on the matter of equilibrium very well when he wrote:

"[P]ositions of unstable equilibrium, even if they exist, are transient, non-persistent states. […] How many times has the reader seen an egg standing on its end?".

(Arthur, 2015, pp. 4-5)

Equilibrium is therefore assumed to be the default position for economic systems to be in and are only perturbed by exogenous shocks, which dislodge the economic agents' preference relations and lead to a general readjustment of supply and demand. The notion of general equilibrium had its inception with Léon Walras, as Murray Rothbard writes:

Since World War II, mainstream neoclassical economics has followed the general equilibrium paradigm of Swiss economist Léon Walras (1834–1910).[1] Economic analysis now consists of the exegesis and elaboration of the Walrasian concept of general equilibrium, in which the economy pursues an endless and unchanging round of activity—what the Walrasian Joseph Schumpeter aptly referred to as "the circular flow." Since the equilibrium economy is by definition a changeless and unending round of robotic behavior, everyone on the market has perfect knowledge of the present and the future, and the pervasive uncertainty of the real world drops totally out of the picture. Since there is no more uncertainty, profits and losses disappear, and every business firm finds that its selling price exactly equals its cost of production.

(Rothbard, 2011, p. 261)

As Rothbard states, here the initial position of the economy is the monotony of general equilibrium, which is in turn only perturbed by exogenous shocks to the prevailing market arrangements. This, with some occasional deviations, has remained the bedrock of reductionist economics ever since its widespread adoption in the aftermath of the Second World War, when, buoyed by its acceptance by the Monetarists and Keynesians alike, reductionism became the default prism through which the vast majority of the economic community was to analyse economic life. Econometrics, perhaps the most "newtonised" of reductionist methods, is based in its entirety upon the assumption of an initial general equilibrium and may thus serve as a good example of Walrasian thought applied in its most consequentially reductionist form.

Conclusion

The development of logical positivism and the broader notion of reductionism has, without a doubt, added to the general strength and predictive power of economic theory. So long as economic phenomena exist at approximate equilibrium, econometrics and associated methods have much to yield in terms of their predictive and explanatory power. However, once conditions of endogenous general or partial equilibrium cease to hold, the ideas of rationality, complete information, and equilibrium are likely to meet significant obstacles. The developments in complexity economics have, ultimately, served to add to the reductionist canon, to complement it where possible and to displace it where its assumptions cannot be claimed to be empirically justifiable. Before turning to the specifically Hayekian elements of complexity economics, we shall therefore first list the positions of complexity economics, in order for us to be capable of a direct comparison.

Complexity Economics

In the following, I shall endeavour to construct a stepwise explanation of the nature of complex economic systems, whereupon I shall elucidate the fundamental founding role of Friedrich Hayek. Juxtaposing Hayek's views—held, in some cases, half a century before they would become widely held in the field of complexity economics—will serve to furnish us with a rarely discussed perspective on Friedrich Hayek's role in the History of Economic Thought. While he is better known for his intellectual rivalry with John Maynard Keynes and his criticism of state socialism, he might be less well known as the harbinger of an entirely new ant alternative empirical strand of economic theory (Hayek, 2007). As we shall come to see, this element of Hayekian thought deserves, at the very least, to gain widespread recognition.

The Individual Elements

Complex systems, as opposed to the linear systems of the reductionist paradigm, exhibit properties which incline the sum-total of their constituent elements to evolve emergent properties capable of feeding back into the individual constituent element's preferences and learning process. Whereas in a non-complex system the constituent elements endow the whole structure with a neatly aggregated, linear set of properties by adding the various heterogeneous parts of a complex system together, doing so with elements which bring forth emergent, complex properties causes them to behave differently than they would had they not been aggregated. As mentioned above, according to the complex view of economic phenomena, the aggregation of the economic agents in an economic model at the microsphere results in the non-linear and non-proportional causation of effects at the macro level which are more (or less, depending upon the system) than a mere representation or aggregation of the results of the optimisation schedules of the constituent agents.

While the reductionist approach assumes the prevalence of rationally maximising behaviour on the part of the systems agents, complex systems are constituted by heterogeneous economic agents, acting according to their bounded rationality. The nature of economic agents in the realm of complexity

economics is entirely a posteriori and empirical, as compared to the partly aprioristic and deductive reasoning applied in conventional reductionist economics.

Furthermore, as Arthur states, complexity economics' agents apply inductive reasoning as opposed to the deductive reasoning assumed to be their modus operandi by the non-reductionist mainstream (Arthur, 2015, p. 6). Accordingly, economic agents engage in an evolutionary process of problem solving, all the while adhering to rule based behaviour. These rules proscribe the agents' behaviour and are acquired and shed according to the agents very own calculus of problem solving (Kirman, 2011). As compared to the microeconomic approach taken by the antireductionist economists, economic agents in complex systems act under incomplete information and further their goals by a long, evolutionary process of trial-and-error. Various fields of science feed into this complex conception of economic agency. Among them are behavioural economics and evolutionary psychology.

Rationality

As opposed to the notion of rationality pursued by the reductionists, Complexity Economics has repudiated the a priori, deductive axioms of neoclassical thought in favour of an empirical, a posteriori approach to reasoning. While, for instance, the Arrow-Debreu framework views the economy as a collection of atomistic individuals reacting to pervasive and attainable price signals (Arrow & Debreu, 1954), Complexity Economics strides the path of bounded rationality (Hayek, 1945). While this restrains the economist in his zeal for mathematical modelling, as Arthur points out, the complexity economist is capable of modelling the economy by means of computation and simulation (Arthur, 2015, p. 10).

Whereas in the Arrow-Debreu Economy the economic agent is necessarily a price-taking, passively evaluating individual, in the anti-reductionist approach, he is a highly complicated "system within a system" (Arthur, 2015, pp. 4-6), engaging in various kinds of problem-solving and trial-and-error challenges, learning and therefore computing along the way which rules to follow and which to discard, and changing his membership of institutions with the passing of time. The common thread in these activities is the continual striving for and

refinement of information and knowledge which, dispersed as it is, imposes upon the economic agent a wholly different set of rationality trade-offs as compared to the Arrow-Debreu agent, according to which he maximizes each and every problem in keeping with a certain set of axioms.

Institutions

In joining together isolated agents and thereby generating a complex system of various scales, we may further observe the creation of institutions, the emergent outgrowths of the mutual association of the individual constituent agents of an economic system. These institutions—or as Burke called them "platoons of society" (Burke, 2004)—emerge spontaneously from the association of individuals and, by their very existence, provide feedback to those agents, changing their evaluations of their external circumstances and thereby altering their preferences, based entirely upon the emergent circumstances which they unconsciously brought about. Enrico Spolare and Romain Wacziag have fittingly described institutions as "rules and norms which regulate and constrain human actions and interactions" (Spolare & Wacziag, 2016, p. 147).

Such institutions can be seen as emergent properties of complex systems, signifying their spontaneous creation by dint of the aggregation of individual, hitherto unconnected elements. When combined, these elements cause an institutional superstructure to emerge which, in turn, influences the individuals involved in its creation. Therefore, a merchant located within a busy marketplace with plenty of competitors is by the very nature of the market institution incentivised to readjust his rules of conduct and preferences as compared to a situation seeing him alone and without competition in a remote village. While the latter scenario presents different institutional overlays, we may at least state its differing level and scale of complexity.

Networks

In so associating, agents give rise to networks of various layers and different scales, connecting ostensibly unfamiliar economic agents with others by varying degrees. Given this network foundation, economic agents embed themselves in mutually recognised and negotiated rules and traditions, affecting their preferences and thus feeding back into the very nature of their constituent parts. The relatively young field of network science deals with the degrees of interconnectivity in economic systems and systems in general. Since the turn of the century and the arrival of digitalisation, the scale and scope of network connectivity in the economic sphere has increased immensely, causing a substantial increase in systemic economic complexity (Barabási, 2016, p. 20ff). Neil Johnson uses the example of information, rumours, and viruses to demonstrate the types of phenomena which benefit from dense networks, meaning they are capable of spreading with often startling speed (Johnson, 2007, p. 98). Consequently, it is of great interest to uncover how individuals and institutions behave under varying levels of interconnectivity.

Equilibrium

Void of their rationality axioms, individuals necessarily have no way of arriving at anything approximating a stable equilibrium, due to their lack of the right information at the right time in the right place (Kirman, 2011, p. 14). Given this limitation, there have been various notions of equilibrium under discussion within the field of complexity economics. For instance, as Arthur states, complex systems exhibit the tendency toward "endogenously generated disequilibrium", as opposed to having a normally equilibrated system disturbed by exogenous shocks (Arthur, 2015, p. 4ff). He gives two reasons for this:

1) According to Arthur, the "fundamental uncertainty" engendered by the bounded rationality described earlier leads the adherents of equilibrium into an infinite regress. For instance, if the outcomes evaluated by the individual agent are unknown, the purely deductive rationality applied to arrive at the equilibrium solution is, by its very nature, impossible to define well-enough, for there is no logical solution to a problem or line of reasoning which itself lacks logical definition. "Uncertainty

engenders further uncertainty", as Arthur states (Arthur, 2015, pp. 5-6). To therefore assume a process amenable to equilibrium analysis is logically impossible, seeing as the fully rational, price-taking agent of the reductionist variety is no longer available to endogenously readjust economic processes toward equilibrium. Rather, we have a substantial lack of both knowledge and rationality making equilibrium impossible.

2) The second factor making equilibrium endogenously impossible is, according to Arthur, technological change (Arthur, 2015, pp. 6-7). As the Austrian economist Joseph Schumpeter once remarked, there exists "a source of energy within the economic system which would itself disrupt any equilibrium that might be attained" (Arthur, 2015, p. 6). The source he meant has, for the most part been called technology and may be defined for our purposes as the knowledge of various combinations of the productive factors in an economy leading toward the production of either a capital good or a consumption good. While equilibrium analyses of the economy often pay lip service to technology's importance and incorporate it into their models, these tend to see technology as an exogenously given, labour augmenting production factor, not an endogenous source of a "permanent state of disruption" (Arthur, 2015, p. 7), leading to cascading change in the economy and sparking further technological progress.

While these flaws in the equilibrium approach are well understood by many of its adherents, the reductionist paradigm has until very recently seemed to be the only attainable, coherent method of productively analysing the economy without sounding esoteric or antiscientific. As Arthur states, we are now in the scientific position to analyse the economy as an ongoing computation, ever evolving through series of events and therefore becoming algorithmic (Arthur, 2015, pp. 10-11). This allows us to analyse economic phenomena hitherto unseen under neoclassical economics with their highly mathematical tools and methods (Arthur, p.11). Alan Kirman and Rajiv Sethi have sought to apply evolutionary dynamics to the search for equilibrium states in complex systems (Kirman & Sethi, 2016, p. 15ff). They apply the notion of bounded rationality to various models meant to describe market phenomena and endow the

economic agent with learning abilities and the capability of making incremental improvements to his set of rules of action. As a consequence of shedding the highly rational concept of homo oeconomicus, Kirman's and Sethi's agents influence their given environments, causing a degree of coevolution with the factors representing selective pressures. The result of their various models is a state of quasi equilibrium in which the population of economic agents is split in two groups which in turn dominate—for example—the price expectations of a financial market (Kirman & Sethi, 2016, p. 25ff). In the periods of one group's dominance, a financial market settles into either a phase of high or low volatility. These phases of relative calm may, according to the authors, be seen as approximating a more conventional notion of equilibrium, allowing traditional Neoclassical models to function with reasonable accuracy. However, as they stress, these periods of group dominance are interspersed by endogenous shocks, leading to a regime switch. During the shock phases, traditional reductionist methodologies cease to function adequately. We are therefore left with the core theme of complexity economics' view on equilibrium being one of endogeneity, whatever the angle of approach. While traditional neoclassical views have emphasized the exogenous nature of shocks which dislodge an economic system from equilibrium, the complexity view leaves us with an endogenous perspective on economic equilibrium and stability, one which is by its very nature more challenging to model.

Evolution

Evolution, though commonly associated with flesh and blood creatures, is a natural process present not merely in various species of animals but is furthermore present more generally.

Broadly speaking, evolution is a process of informational change and can occur in several ways. For the purposes of this paper, we shall focus on the best known variant of evolution: Darwinian evolution. As Mayfield states:

> "[…] here selection acts on stored information that is used to make something happen. It is the body of information that is updated during the selection process […] objects do not evolve; it is the underlying information which creates the objects that evolves."

(Mayfield, 2016, p. 49)

In the economic context, the information which is propagated could be equated with notions such as rules of behaviour, conduct, and tradition. These are the rules which an economic agent follows to his or her economic advantage or detriment. Therefore, in a truly Darwinian sense, within the complex adaptive systems of economics, evolution leads to either the propagation of elimination of such rules belying the individual agents' or institutions' behaviour. If, therefore, a company attempts to comport itself according to an unprofitable set of rules such as, for example, giving away money to its competitors with nothing in return, it will find itself at an evolutionary disadvantage with regards to its competitors, who may have inherited or adapted a more advantageous set of rules. As Wilson states, these changes in individual preferences in turn alter the structure of the environment to which all other economic agents are forced to adapt, hence, they coevolve as a group, as a system (Wilson, 2016, p. 31ff). In the scheme of individual Darwinian evolution by natural selection, we find the process of evolution proceeding as shown in the following table:

Inputs→	Probabilistic→ copying	Outputs→	Projections→
←Selection←			

Table: Own, based upon (Mayfield, 2016, p. 49)

This process of evolution is directly applicable to the evolution of the ideas, rules and traditions which constitute the hinge of economic life. In this context, it would certainly be equivalent to say that the inputs displayed above don't denote genetic information but the ideas, plans, and concepts which make up the centre of the economic agents decision-making process. These ideas are subjected to the economic equivalent of probabilistic copying which comes to mean the process of human evaluation of ideas which, by its very nature, is imperfect and leads to mistakes as well as successes. At any rate, the output may be viewed as the concrete manifestation of the ideas selected in the

previous step; one might think of a new product being offered on the marketplace, conceived according to the ideas at the beginning of the chain. Finally, the projections of the output are the actual market consequences of the new product, which may consist in its commercial success or demise. Ultimately this process of selection allows only the most well-adapted of ideas to survive.

As Mayfield relates, we may view the process of evolution—the "Engine of Complexity", as he calls it—as the central natural process of the development of the information[2] underlying the entire universe (Mayfield, 2016, p. 47ff). As it relates to economic systems, however, Mayfield distinguishes between two types of evolutionary environments: Firstly, he mentions the internal environment of the mind, which conceives of and partakes in the evolution of rules, statements, strategies, and preferences, which in turn evolve and adapt to their environment according to the Darwinian mechanisms outlined above. Secondly, he raises the external environment, the realm of material objects such as biological organisms and other worldly objects which may evolve in a variety of ways, some of them not Darwinian. In the economic realm, the interplay of the two gives rise to market behaviour, according to Mayfield, which does not evolve (Mayfield, 2016, p. 48ff).

Focussing on the economic agents as individuals or groups, as opposed to their environment, he furthermore distinguishes between individual evolution and social evolution (Mayfield, 2016, p. 53ff).

Individual evolution takes place in the brain of the particular economic agent where, through the process of learning and trial-and-error, a new "population" of mental models[3] are evolved according to their fitness as demonstrated by their capability of endowing their economic agent with more success in market transactions. These models may include rules of conduct, rules of thumb, traditions and other customs. Provided that they are exposed to the

[2] It is important, at this stage, to conclude with a robust definition of "information". While modern developments in information technology go a long was to proving a hint as to the nature of information, its realm of relevance is broader still. Information may be thus defined as the underlying rules according to which purposeful things are organized. If, for instance, a line of code states "1" as opposed to "0", this, in combination with many other such binary distinctions encodes a specific state of affairs, rule or instruction.

[3] According to Mayfield, mental models are the results of parts of the brain tasked with pattern recognition and are meant to precisely approximate real world phenomena external to the human being (Mayfield, 2016, p. 56ff).

manifestations of other mental models in a society, these models might find widespread acceptance or universal derision. At any rate, their nature primes them for being evolved incrementally through time.

Hayekian Complexity

In light of the definitions provided above, Friedrich Hayek's contributions to Complexity Economics are manifold. Partly due to his investigations into behavioural psychology (Hayek, 1952), Hayek had by the 1950s developed a cutting edge definition of human cognition and bounded rationality. In a time void of any coherent and serious pursuit of complexity science, he proved to be one of the first to introduce notions of rules, order, and systems. While the contributions treated in this work are wide-ranging and substantive, they oughtn't be construed as a systematic treatment of complexity economics. While Hayek expounded many valuable theories in this regard, the serious systematisation of complexity economics and complexity theory as a whole only started in earnest by the 1980s. With this in mind, Hayek's contributions are frequently startling in their insightfulness and, together with his mentor Ludwig von Mises, Joseph Schumpeter and others, would place him at the front line of a movement of antireductionist reaction against the then orthodox doctrine of reductionism.

Rules and Order

In his 1982 classic "Law, Legislation and Liberty" (Hayek, 2003), Hayek was the first economist to lay down a systematic vision of the human search for rules according to which one might be able to govern behaviour successfully in an economic system. In so doing, he criticised the Cartesian, rationalist reductionist approach, which seeks to construct rules governing human actions and interactions in the abstract, deprived of any empirical foundation (Hayek, 2003, p. 10). The René Descartes approach saw body and soul as separate entities, capable of their own particular levels of inquiry, and bestowed upon

the soul deductive reasoning powers pertaining to the realm of the material reality. In the area of economics, the inquiry sought after had always been (and remains) the postulation of laws or rules according to which economic agents act in matters of economic life. These, according to Hayek, are the economic science's equivalent of the natural laws found in other sciences (Hayek, 2003, p. 15ff). To Hayek, however, man's reasoning abilities are insufficient to avail himself of the knowledge required to make such constructivist statements. Much like his contemporary and friend, the philosopher of science Sir Karl Popper, Hayek saw the economist's role in the scientific enterprise as incrementally attaining new knowledge relating to the rules according to which the market economy operates, as opposed to making grand pronouncements as to the ideal structure of the given economic system (Popper, 2003) (Hayek, 2003, p. 29).

More generally, rules were seen by Hayek as "If-Then" statements pertaining to real-world phenomena and seemed to him to denote a causal relationship in the matter under investigation (Hayek, 2003). Thus, "If this stone is allowed to fall to the ground under laboratory conditions, then it will reach a perfect standstill after X seconds." In economic life, these rules might be expressed in somewhat different terms. For instance, "If, all other things equal, demand for commodity X rises, then its price must rise proportionally.". These rules are, says Hayek, given by nature previously and, together with other scientific rules, constitute that part of reality discoverable by man, according to which he has to conduct himself if he intends to attain his goals (Hayek, 2003, p. 15ff). The economic agent's main role is, thus, to incrementally add to the efficacy of his already acquired rules. Thus, an entrepreneur succeeds provided he attains rules suitable to his business environment. This directly mirrors the approach taken by modern complexity theorists who generate algorithms designed to replicate this

Knowledge and Rationality

Hayek's perhaps best known contribution to economics is his work relating to the nature of human knowledge and its use in human societies (Hayek, 1945) (Hayek, 2006). In it, he stresses the absurdity of economic planning due the inherent degree of dissipation of relevant economic knowledge. In "Law,

Legislation and Liberty", Hayek references what he calls the "synoptic delusion" committed by the constructivist rationalists, wherein the coherence and aesthetic of a neatly laid-down plan seduces them into dropping all inhibitions regarding their own law of knowledge, resulting in what one might under our circumstances be tempted to call "scientific hubris" (Hayek, 2003, p. 15). Such hubris may be seen as manifested in the assumptions undergirding reductionist economics, their assumptions being such as to place the economist in the position of a social engineer, capable of remaking economic systems according to some rationally acquired knowledge and assumptions derived from rationality alone.

Spontaneous Order

Based upon the previous two Hayekian Ideas, we now come to perhaps the most striking pre-complexity theme in Hayek's work. Above, we introduced the topic of complexity by referencing its one absolutely necessary condition: a state of affairs wherein individual agents with their own rules and preferences are joined in various institutions, forming a network and all the while bringing about aggregate effects, which no individual actor purposefully brought about or designed. Adam Smith famously referred to an idea very similar to this with his invisible hand, steering society in a benevolent manner without any of the constituent agents planning this in advance (Smith, 1999). Very much in the Smithian spirit, Hayek elaborated on what he calls "spontaneous order", as opposed to a rationally designed, Cartesian order (Hayek, 2003, p. 34ff). The two are referred to by the ancient greek "cosmos" and "taxis" in "Law, Legislation and Liberty", the former describing a naturally grown or evolved order, the latter denoting a consciously designed order. Furthermore, he holds that spontaneous order as such results ultimately by obeying the already given yet partially undiscovered rules of nature (including, of course, the rules of economics). Therefore, given a society made up of individuals and organizations, those entities or agents flourish, which are capable of best harnessing their own limited knowledge according to already existing rules (Hayek, 2003, p. 44ff). Not only does this foreshadow the notion of complexity economics, now well-established, that individuals or organizations associating with one another involuntarily create a "meso-layer" of feedback into their own

preferences and mental models, he also includes an evolutionary component from the very beginning (Hayek, 2003, p. 22ff).

Koppl's BRICE Themes

To draw on what was written above, Roger Koppl states that there are five core themes—he calls them BRICE themes, with their first letters in mind—commonly ascribed to Hayek which he sees to be highly relevant to complexity economics (Koppl, 2009).

1) Bounded rationality

Hayek, following the mathematician Kurt Gödel's incompleteness theorem, held that there was a logical fallacy in assuming man to be capable of attaining knowledge sufficient to understand human societies in the depth required as to successfully plan outcomes in complex societies (Koppl, 2009). The human mind, by its very nature, does not permit of such conceited analysis, Hayek claims. This, then, logically precludes any central planner from arrogating to himself the capability of acquiring enough knowledge as to steer a human society in a manner he would like to attain (Rosser, 2015).

2) Rule-following behaviour

In keeping with his generally evolutionary philosophy of science, Hayek proffered a necessarily rule-following, agent-based view of human societies. As it concerns economics, this implies the introduction of (positive and negative) feedback loops capable of introducing non-linear phenomena into an economic system permitted to operate thus. This view chimes well with the later-to-be-developed complexity analysis of individual economic agent's behaviour under conditions of bounded rationality and as a member of a complex adaptive system. Hayek thus pioneered the computational view of man in economic life, characterizing him as learning new rules of conduct, optimising them incrementally, and, if necessary, discarding them when they fail to adequately account for certain patterns encountered.

3) Institutions

Though there always was and still remains a great deal of acrimony between various sections of Austrian economists and Institutionalists, there remains a core acceptance of various institutional aspects of economic analysis. Institutions, in the Hayekian sense, may be understood as the accumulated results of previous intra-systemic feedback. Edmund Burke referred to a very similar notion as the "little platoons" of society, the communities within which man partakes in order to form an identity and reduce the overwhelming complexity of the external world (Burke, 2004). For this reason, institutions serve the purpose of moderating frameworks for human agency.

In line with Enrico Spolare and Romain Wacziarg (Spolare & Wacziag, 2016), institutions are here defined as "rules and norms which regulate and constrain human actions and interactions" (Spolare & Wacziag, 2016, p. 147). In defining his "game of catallaxy" (Hayek, 2003, p. 267ff), Hayek lays down a process engaged in by economic agents whereby they associate voluntarily, in the process only to establish rules-based relations governing their normative valuations, their estimation of what they ought to do (Hayek, 2003, p. 276). In other words, by doing nothing but going about their daily business, economic agents discover (as if aided by an invisible hand, to set us in mind of Adam Smith's partly applicable analogy (Smith, 1999)) the rules necessary of the conduct leading to their very own economic flourishing. While this is not meant to postulate a normative framework for economic policy, it foreshadows exactly what complexity economists such as W. Brian Arthur have since called the "meso-layer" of economic cooperation, a layer between the reductionist notions of the micro- and macro level of economic analysis. (Arthur, 2015, p. 12). Seeing as Hayek characterised this emergent property of human relations as a game, we are also justified in posing this as his description of an economic agent's interplay with the feedback he gains from the institution, the creation of which he was an often unwitting part of.

4) Cognition

Strongly opposed to the conventional analytical tool "homo oeconomicus", Hayek pioneered a psychological notion of pattern recognition and computation by economic agency. Though, this point may be seen as being closely related to the first point (bounded rationality), it counters one of the main axioms inherent in positivistic branches of economics, that of "complete information", therefore implying that man is never capable of knowing (much less computing) the almost limitless amount of information to which he is in theory privy.

5) Evolution

Hayek saw the process of evolution as a humbling, incremental, and decentralised opposite to the rationalist constructivism of the reductionists and logical positivists. Of the two approaches Hayek wrote:

> "The first [constructivism] gives us a sense of unlimited power to realise our wishes, while the second [evolution] leads us to the insight that there are limitations to what we can deliberately bring about, and to the recognition that some of our present hopes are delusions."
> (Hayek, 2003, pp. 9-10)

The process of evolution that Hayek describes is, as it were, a prototype of the complexity view of the economy. For in it, Hayek, writing from 1945 to the 1970s, lays down principles which other parts of the economic community would only start discovering in the 1980s, primarily at the Santa Fe Institute in New Mexico, the pioneering institution for research into economic notions of complexity.

Hayek's own view of evolution centres around the economic institutions mentioned earlier. They are given rise to through the distinctly Hayekian process of spontaneous order, wherein institution come into being without a rational design behind them and prove themselves in the "game of catallaxy", with the most successful maintaining their existence (Hayek, 2003, p. 275ff). When viewed through the lens of modern definitions of institutions as assortments of rules and customs lending themselves to a computational, algorithmic process of complexity (Spolare & Wacziag, 2016), it is astonishing

that Friedrich Hayek was able, decades prior to these important developments in complexity economics, to define the central market process with regards to economic agents and institutions with such accuracy. It is therefore justified to state that Hayek can be said to have been thoroughly vindicated in his writing on economic institutions.

The Hayekian Legacy

While Friedrich Hayek has been adopted into the "pantheon" of complexity economics' precursors, his influence lies not merely in influencing this particular field of economic inquiry. While his significant work "Law, Legislation and Liberty" provides a compelling and coherent vision of economic and social evolution, it is by no means restricted to this domain alone. As its title suggests, Hayek provided an analysis of law and legislation which, in methodological terms, unifies neatly with the economic angle of his inquiry. Ultimately, Hayek was on the cusp of what was only later defined in any coherence and which was alluded to earlier: the unification of scientific, moral, and aesthetic inquiry under the principles of varying levels of complexity, evolution and emergence. Seeing as he was focussed on the economic realm, this naturally was not his centre of attention. But the logical consequence seems all too clear. Hayek proposed a scientific approach to economics and, in line with the thinking of his friend Sir Karl Popper, based it upon the foundations of an antireductionist scepticism, leading to a general distrust of a left-wing, messianic vision of economic life and he instead favoured letting decentralised economic actors acquire the knowledge necessary to "run" a highly complex edifice such as a modern economy. His contributions to complexity economics will doubtlessly stand the test of time, seeing as they incorporate not merely an approximate delineation of institutional and individual evolution, but also include an entire economic epistemology which precludes centralistic and socialistic human error from eliminating the advances made by in his vaunted "game of catallaxy" (Hayek, 2003, p. 275ff).

As it relates to the broader methodological conflict between the reductionist and antireductionist factions of the economic community, the assessment of the

rise of complexity economics made by historians will surely result in their deeming it a welcome addition to the rightfully established and useful aspects of reductionism and logical positivism. As Friedrich A. Hayek tried to convey with his work, no one scientist can claim to have an exclusive hold in the correct methodological paradigm for all of economic inquiry. Upon the whole, if the ascent of complexity economics will continue, a plausible outcome would be a new type of scientific division of labour, whereby economic phenomena at approximate equilibrium are analysed using the proven and tested reductionist methods of economic analysis, leaving the areas of severe shock and distress to the antireductionist methods of inquiry. As so many economists of the past saw, a too narrow-minded approach to science may lead to a distinct lack of reason in all the wrong places. After all, who could have predicted 120 years ago the upheaval wrought unto the accepted methodological paradigm of physics by Einstein's theories of relativity and who would want to turn back the clock at this late, fascinating hour?

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