In search of a suitable heuristic for evolutionary economics: from generalized Darwinism to economic self-organisation.

Foster, John

University of Queensland

16 February 2021

In search of a suitable heuristic for evolutionary economics: from generalized Darwinism to economic self-organisation[1]

February 2021

John Foster, School of Economics, University of Queensland, Brisbane, Queensland, Australia

j.foster@uq.edu.au

1. Introduction

The field of evolutionary economics has gone from strength to strength for almost four decades now, mainly sparked by the seminal books by Kenneth Boulding (1981) and Nelson and Winter (1982). However, as Nelson (2020) has pointed out, the advances in this expanding field have been virtually ignored in the mainstream of economics and most of the key contributors are now located in business schools (Hodgson (2019)). An important reason for this lack of penetration has been the fact that the sub-fields of evolutionary economics do not have a shared heuristic, unlike the mainstream (Witt (2008)). But, from the above mentioned seminal contributions onwards, Darwinian biological analogy became popular as a 'meta-heuristic' (Winter (2014)). However, it eventually became accepted that using an analogy from another discipline has its limitations (Hodgson (2002)). Instead, Darwinism began to be viewed in a different way.

Price (1970, 1972) provided a formal representation of an evolutionary process that became central in neo-Darwinian models of biological evolution. Metcalfe (1998) and others demonstrated that economic evolution can also be expressed in the Price Equation and that this is not just a biological analogy. If there is an available market niche and a distribution of fitness (or variety) amongst entrants to it, differential growth ensures that the fastest grower will come to dominate. So, Metcalfe (1998) did not see the Price Equation as a representation of evolutionary dynamics that is specifically Darwinian. However, it was not long before some evolutionary economists saw it as neo-Darwinian in character, provided that a replicator/interactor distinction can be made. What was previously known as 'Universal Darwinism' became known as 'Generalized Darwinism' (GD) in evolutionary economics. Hodgson and Knudsen (2010) provide a comprehensive treatment.

Frank (1998) argued that the Price Equation, despite being a tautology, has value in evolutionary science, because it can be used to build theoretical models that are genuinely evolutionary in form. The neo-Darwinian mechanism, embodied in the GD heuristic, is one of these. Despite the fact that Hodgson and Knudsen (2010) must be applauded for explaining precisely what neo-Darwinism means in evolutionary economics, is it the right choice of heuristic for evolutionary economics and,

[1] I would like to thank Kurt Dopfer, Stan Metcalfe, Ulrich Witt and Brendan Markey-Towler for their comments on earlier drafts of this essay. However, all errors, misinterpretations and omissions remain my responsibility.

furthermore, is there a role for this kind of heuristic at all, bearing in mind the fact that economics is a different kind of science to, for example, physics or biology? Lawson (1997) argued to the contrary and, instead, offered the empirically grounded, bottom-up methodology of critical realism which does not rely upon a heuristic of this kind but still deals with processes that involve evolutionary change. Also, economic historians, such as David (2007), have argued that research in evolutionary economics should make the historical path dependence we observe in economic processes the core starting point in evolutionary economic research. However, few deny that competition plays a role in economic change, but making neo-Darwinian selection the core mechanism in evolutionary economic analysis is another matter.

It will be argued here that the adoption of a GD heuristic by some researchers, despite the very best of intentions, was a wrong turn in evolutionary economics because it cannot be connected directly to empirical research using historical data and, therefore, cannot offer a methodology for undertaking such research. The result has been a tendency towards more fragmentation, rather than unification, of the different strands of applied research in evolutionary economics (Robert et al. (2017)). For example, a great deal of useful research in evolutionary economics is conducted in the field of innovation. Indeed, Winter (2014) contended that the field of evolutionary economics has always been centred upon understanding the causes and consequences of technological change. Furthermore, innovation research has had a significant impact upon policy in some countries (see, for example, Dodgson et al (2011) in the case of Australia). Since innovation is all about the generation of variety, GD, with its focus on competitive selection across a given variety set, does not seem to be a very useful analytical framework for generating theories and hypotheses to test in the related fields of innovation and entrepreneurship. So, over the past decade, there has been an increasing separation between theoretical work employing the UD heuristic and empirical studies of innovation.

So, the objective of this essay is, first, to explain that, even though it is fully accepted that competition has a role to play in economic evolution, the GD heuristic, when it is relied upon too much in trying to understand economic change, can lead to misleading conclusions. In particular, the presumption that competitive selection occurs within a fixed market niche, poses a fundamental problem (Gatti et al (2020)). Secondly, it will be explained why, instead of an abstract heuristic like GD, there is a more urgent need for a grounded heuristic in evolutionary economics that can connected to a methodology that can be used, directly, in empirical research in microeconomic fields such as innovation and entrepreneurship, and in macroeconomic studies of economic growth and development. An actual evolutionary economic process involves the intertwining of non-random variety generation, representable as self-organisation, and competitive selection from a given variety set. Both can happen simultaneously in the economic domain, but, it is argued, the former offers a better methodological starting point for empirical research in economics since, the generation of variety is non-random, to a considerable degree, and cooperation is widespread. Competitive selection is clearly central in biological evolution because the variety generated is largely random. But, in economics, cooperation and complementarity are inevitable accompaniments to the non-random processes of entrepreneurship and innovation and this has been repeatedly observed in many different socio-economic contexts. Thus, the degree to which competition is important depends upon the systemic context that we are dealing with.

2. Generalized Darwinism

Over the past two decades, GD has risen to prominence as a popular heuristic that provides a formal representation of an ontology, or 'way of thinking,' about economic evolution which portrays evolution as the outcome of a competitive struggle for scarce resources (Witt (2008)). Neo-Darwinism is offered, not just as a biological analogy to be employed in the social sciences, but as a theoretical homology capturing, in an abstract way, a general mechanism that is deemed to be present wherever, and whenever, evolutionary change is occurring. Two of its main proponents, Hodgson and Knudsen (2010), building upon, for example, Metcalfe (1998) in evolutionary economics and a range of contributors to the development of Universal Darwinism in biology discussed by Knudsen (2004), argue that all evolutionary processes must exhibit three stages: variation, selection and retention, with selection being the key mechanism that enables evolutionary change. Although the Price Equation is not a Darwinian construction, but a general equation about the evolutionary consequences of differential growth, Hodgson and Knudsen (2010) render it neo-Darwinian by arguing that the replicator/interaction distinction, accepted widely in biology, can also be identified in economic contexts. But, importantly, they do remind us that GD is a heuristic that does not provide a methodology directly applicable in applied research using data on a historical continuum. Instead, it is seen as an important aid to theoretical construction, and the resultant framing of, specific hypotheses concerning evolutionary change in particular times and places.

The development of the GD heuristic has been very useful because it has clarified what is actually meant by neo-Darwinism in evolutionary economics. Confusions have been cleared up. However, useful as this heuristic may be in thinking about economic evolution in a broad sense over long periods, it can offer little detail about actual history or about the source of variety (Buenstorf (2006), Vromen (2019)). In biology it is generally presumed that variety is due to the emergence of random mutations in replicators. Although this may be so in biological contexts it is difficult to accept in economic contexts (Liagouras (2017)). Presuming randomness in the generation of variety shifts most of the evolutionary action on to competitive selection. But, in economic contexts, the generation of variety is not random and the empirical distinction between replicator and interactor is very blurred. Take for example, ‘routines’. From Nelson and Winter (1982) on, they tended to be viewed as replicators whereas, Metcalfe (1998), argued that they were interactors, with knowledge being the replicator. What this suggests is that there is often no clear distinction between replicator and interactor in economic systems (Nelson (2006), Levit et al (2011)), therefore, GD is not a general heuristic, even though it can be captured in the Price Equation. Also, the variety set is never static in economic cases. Typically, a competitive process over a given variety set will be overtaken by further changes in variety, due to self-organisation, inducing a historical process that does not have a clear competitive conclusion. What we have, instead, is a layered process of self-organisation as new market niches emerge and old ones become obsolete (Gatti et al (2020)).

Now, we know how important core heuristic constructions are in the natural sciences. They connect ontologies with empirical methodologies that, if widely adopted, become scientific paradigms. But in, for example, physics, the core heuristic is built upon established physical laws, enabling it to have a direct connection with hypotheses tested in controlled experiments. In biology, the neo-Darwinian heuristic, with its sharp replicator/interactor distinction, is on strong ground because it can be connected to the operation of energy seeking dissipative structures confronting the Second Law of Thermodynamics, placing it on a solid footing to guide research in fields as diverse as palaeontology and genetics (Schneider and Sagan (2005), Annila and Salthe (2009)).

Long ago, economists knew that, to be viewed as scientists, they too, would have to have to be seen to have paradigms, backed by heuristic devices representable in mathematics. (Lawson (2019)). So economists created heuristic constructions similar in style to those found in 19th Century physics. In the post-war era, the favourite in mainstream economics has been neoclassical economic theory (NET) and its macroeconomic companion, the theory of general equilibrium (GET). But these constitute analogies, not homologies and, therefore, they were not, and could not, provide the basis for a *scientific* paradigm. What emerged were faux-paradigms in microeconomics and macroeconomics that were, misleadingly, connected to the pioneering economic ontology of Adam Smith (1776).

There is no prospect of operationalising either NET or GET directly in empirical settings with a historical dimension. Some kind of *ad hoc* bridge is always necessary (slow adjustment and expectation delays being favourites). An alternative is to construct a simulation of an abstract model derived directly from the neoclassical heuristic and, using a judicious selection of parameters (*adhockery* again), calibration is undertaken. There is an illusion of science at work when, in fact, it is the prior conventional beliefs of the researcher that are pivotal. And, of course, being based upon beliefs, neoclassical heuristics have been resistant to contradictory scientific findings emanating, for example, from psychology. *Ad hoc* modifications of assumptions have been made on the fringe, such as asymmetric information and incomplete markets, but the unrealistic core beliefs have been widely retained. What we see is a lot of scientific looking mathematics which turns out to be, often unintendedly, ideological in nature, rather than scientific.

Turning to GD in economic contexts, there is a strong similarity, in style and intention, to the dominant neoclassical heuristic, in the sense that it looks like it provides the basis for a scientific paradigm, but it cannot because there is no direct connection to an empirical methodology that can be applied in research, using historical information. Instead, a deduced general mechanism, specified abstractly, is deemed to be lurking behind the entanglements of economic history. Those, such as Witt (2004), who have considered the operation of GD in biological and economic settings has not found convincing evidence of a GD homology, although there are other important shared features with biology that need to be understood (Cordes (2006)). So the problem with NET and GET, also affects GD – its presumed operation at the core of evolutionary economic processes is a product of belief. So it is vulnerable to exploitation by those promoting ideological view that inducing competition is the key to economic progress, despite sound evidence by, for example, Ostrom (1990)) that the degree of cooperation seems to be more important.

But it is not the question of ideological capture that matters here, it is the methodological impact that GD has upon evolutionary economic research. It encourages researchers to build their models around a presumed core process of competitive selection that is a special case of the Price Equation and to seek out aspects of reality that conform to this perspective (Vromen (2012)). If the GD mechanism is not, in fact, lurking behind the historical data, then misunderstandings and misinterpretations can easily arise. Turning again to the mainstream, the experience of the Global Financial Crisis demonstrated, vividly, how basing models upon a dominant abstract heuristic, the GET, led to a serious misunderstanding of how the economic system operates with significant social costs. And the unwillingness of many economists since to abandon the GET heuristic is further evidence that we are dealing with beliefs, not science.

Generalized Darwinians might well protest that their heuristic abstraction is fundamentally different in nature to GET and NET and, indeed, the ontology appealed to is very different. For example, Aldrich et al (2008) argued that GD is about non-equilibrium historical processes but, in point of fact, the Price Equation, upon which GD is built, has an equilibrium solution that is rather trivial, given that it is a tautology. Aside from the defence of GD, the article reads more like a broader defence of the choice of an evolutionary economic perspective on economic history with competition playing an important role (Mokyr (1996)). This can only be applauded but, as with GET and NET, the abstraction is not in the historical domain and, therefore, is not very useful in empirical research that employs historical data. Of course, there will be particular historical periods where the chosen abstraction has some explanatory value in conditions that approximate the assumptions made in constructing it. 'Ways of thinking' are, after all, products of people experiencing actual cases and abstracting from them, as Leon Walras did when observing the operation of the Paris Bourse. But, in the rough sea of unexplained historical dynamics, a favoured heuristic may turn out to be no more than a special case that was, unjustifiably, generalized.

So the problem with GD in economics is that it belongs to a class of heuristics that that can be viewed as unscientific because they are not built upon the underlying operation of an empirically established general law (or laws) but rather beliefs based upon observations of particular cases. And what is the practical benefit? For example, it is not necessary to invoke the GD heuristic to tell a researcher that competition operates in economic evolution, nor do we need GD to tell is that there is variety and replication. A good scientific heuristic tells us more than the obvious, it should enable us to discover counter-intuitive understandings that can result in the formulation of novel hypotheses that are not obvious. GD doesn't seem to do this in economic settings, partly because the conventions used, and primarily developed in biology, are difficult to define and identify. As Hodgson and Knudsen (2010), admit, use of the replicator/interactor distinction is difficult to operationalize (Levit et al (2011)). There is no denying that competition is a process that operates in the process of evolutionary change. What matters is what it actually constitutes in socio-economic systems. References to struggles for scarce resources, etc., are not enough.

There is no issue with the Price Equation upon which GD is constructed. The use of tautologies with systemic meaning have proven to be useful in theory development in economics, as was the case with Harrod's growth equation, which enabled the development of the radically different growth theories of Robert Solow and Nicholas Kaldor, via behavioural hypotheses concerning its components. And there is the case of Keynes' income-expenditure identity upon which the very different post-Keynesian, neo-Keynesian and monetarist macroeconomic theories were built, again by constructing different hypotheses concerning its components. Tautologies, or identities, grounded in the logic of a complex system, are very useful in the pre-scientific phase of examining the implications a proposed theory upon the inherent logic of the system under consideration. But, if the theory in question is not founded upon an empirically verified law or historical tendency, as was the case, for example, with Solow's theory of economic growth that used the GET heuristic, then we are in the domain of belief, not science. We cannot conduct valid empirical tests emanating from such theories.

So the question arises: can we discover any heuristic that can provide a general analytical framework for actual evolutionary economic research? In trying to answer this question it is useful to go back to Alfred Marshall (1890) and remember his warnings about over-using abstract, timeless generalisations in economics (Foster (1993)). To him, neoclassical economic theory was a heuristic only relevant to research in particular settings and he knew that non-economic factors had also to be taken into account. So, for example, culture and institutions were important for Marshall in clarifying the restrictions and opportunities that an economic decision-maker faces. He also knew that NET is not very relevant in states of uncertainty where evolutionary processes are operative. However, his informal representations of economic evolution were more self-organisational than Darwinian (Foster (1993)). But most neoclassical economists did not build upon his evolutionary intuitions and his associated concern with the role the rules embodied in culture and institutions.

Instead, it was Veblen (1898) and the American Institutionalists who were to stress the importance of institutions, and the cultures within which they sit. And Darwinism, as understood in the early 20th Century, was used as an analogous way of conceptualising competition that was starkly different that adopted in neoclassical economics. But it was not seen as the primary driver of economic evolution. It was creativity and cooperation that were central. Later institutionalists, such as John Commons, would cease to use the Darwinian analogy at all. For him, culture and institutions were not the product of random mutations and the replicator/interactor distinction was not made. Institutions and other socioeconomic rules were viewed as deliberative constructions and, therefore, endogenous in the economic system. So the conditions for Darwinian natural selection were mostly absent. Through the later lens of the Price Equation, the tendency of differential growth to lead to dominant rules was primarily self-organisational: what Hayek (1973) was to label as “spontaneous order” in the more restrictive neo-Austrian sense. In neo-Darwinian language, interactors devise new replicators and these are adopted by other interactors in a historical feedback process that contains both cooperative and competitive elements.

But such a perspective pushed economics towards the study of history and away from looking like a conventional science. And institutionalists paid a heavy price for this, losing the influence they had on policy in the early 20th Century in the United States. By the 1950s, they were virtually eliminated from the mainstream of the economics discipline. So not having a general ‘scientific-looking’ heuristic had fatal consequences, even though it had been institutionalists, such as Wesley Mitchell, that were pioneers in economic data collection and applied research in economics with two of their number, Simon Kuznets and Gunnar Myrdal, ultimately winning the Nobel Prize.

3. Economic Self-organisation

Modern evolutionary economics stems, not so much from the American Institutionalist tradition but from that of Joseph Schumpeter (1934). He admired the elegant logic of GET and NET but rejected them as very useful in understanding growth and fluctuation in economic systems. He provided an evolutionary perspective but, quite deliberately, did not apply a Darwinian analogy. His ontology was different: he saw economic evolution as primarily about creativity and cooperation. So he focussed upon entrepreneurship and innovation, which we can now identify as an early acknowledgement that economic growth is a self-organisational process (Foster (2000)). For him, economic evolution was characterised by coherent historical phases of growth of different lengths and intensity. The longer upswings were attributed to the actions of entrepreneurs diffusing innovations, with a focus upon technological, rather than cultural or institutional, innovations undertaken in states of uncertainty. However, Schumpeter's evolutionary perspective, despite his fame and influence in the United States, was ignored by most mainstream economists in the post-war era. He offered no heuristic that could compete with the mathematics of NET and GET. Instead, his ontology became of interest to researchers in business schools, rather than economics departments, where entrepreneurship was of central interest. When we look at the burgeoning literature on entrepreneurship and innovation, we see very little evidence that researchers used a Darwinian analogy, never mind the GD heuristic.

If evolutionary economists cannot use an abstract heuristic like GD to do science, because there is no direct connection between it and established laws or with the historical data at our disposal, where do we go? The answer starts with the Second Law of Thermodynamics, as does modern neo-Darwinian theory in biology. If we build upon an established physical law, we are on our way to providing a heuristic that can yield a scientific paradigm. All economic systems that we observe are subject to this law and economic structures within them are built deliberately to negate its operation through the absorption of free energy to maintain structure and to do work. So when we argue that economic systems behave as dissipative structures, we are not dealing with abstraction, but with recurring processes that we can readily observe in real time. Here, were really are dealing with a homology across disciplines.

The dissipative structures that we deal with in economics are of a different kind to those observed in physics or biology (Allen (2005), Foster (2005a), Witt (2004)). They involve the deliberate application of acquired skills and knowledge in the design, construction and operation of economic structures.

Such structure is a product of the imagination, in which an aspirational goal is formed and systems are constructed to try to achieve such a goal (Foster (1987)). Whereas biological dissipative structures directly seek out energy gradients to exploit, economic dissipative structures try to discover knowledge gradients that can enhance their capacity to exploit new energy gradients. This involves either the entrepreneurial discovery of innovative new connections between existing elements (Kirzner (1997)) in a complex system or new connections with new elements conjured up in the imagination (Shackle (1972). This is the process of economic self-organisation, whereby an entrepreneur and her team can make an economic structure more complex and larger without exogenous intervention (Foster and Metcalfe (2012)).

Complex systems theory tells us that it is essential for survival that economic structures are ordered and, thus, have prior commitments in each time period and, therefore they must exhibit some degree of time irreversibility (Arthur (2014), Gillesa et al (2015), Foster (2017), Robert et al (2017), Witt (2017)). But we know that such rule-dependent structure cannot be sustained indefinitely: the operation of the Second Law of Thermodynamics is not always very obvious but this law truly does lurk in the shadows. The existence of this law means that all dissipative structures must organise to try to nullify it via maintenance, repair and replication. Biological structures rely upon reproduction to replicate but economic structures have no strict equivalent to a genome. But they do have a founding structure, that is, to some degree, irreversible, that can be decisive in determining life and death (Hannan and Carroll (1992)). However, such systems are not fully closed and new knowledge gradients are always available to enable some economic structures to survive, not by replicating themselves but by adapting their core structure.

Entrepreneurship results in the emergence of new structure and the adaptive potential of existing ones. But this always involves tension because it is the polar opposite of pre-committed, meso-rule-bound behaviour that is necessary for the structure to function effectively (Dopfer et al (2004)). For this reason, much of entrepreneurship that involves radical innovation occurs in emergent, not existing, structures. And, because entrepreneurship is mostly conducted in uncertainty, there must be a great deal of failure (Lane and Maxfield (2005)). Discovery of exploitable knowledge gradients is not easy (Nelson (2016)). Most failure is not because of the operation of competitive selection but because entrepreneurial plans turned out to be non-viable.

In biology, it is argued that random mutations are ‘mistakes’. In other words, the main evolutionary story is based upon the emergence of genetic errors. But in the economic case, this is untenable: entrepreneurial efforts to develop new products and new technologies are not errors, they are deliberative choices. But neither are they rational, in the standard economic sense of the word, because, as noted, they are undertaken in states of uncertainty. Exploration, experimentation and inductive tinkering are the kinds of behaviour that *homo creativus* exhibits as she seeks to achieve an aspirational goal (Foster (1987)). Just as we are hard-wired to maintain order in the complex economic systems that we inhabit by adhering to meso-rules, so we are hard-wired to search for, and enter, new market niches, if the rules permit us to do so. It is this emotional driver that is the 'micro-foundation' of self-organisation, as recognised long ago by, for example, Veblen (1914/2006) and Scitovsky (1976) and confirmed in much of modern behavioural economics.

4. Niches and Scale

Economic self-organisation offers us a distinctly different heuristic to GD stemming from a different ontological view of evolution in economic systems. For economic self-organisation to occur, there must be an available market niche to enter (Kauffman (1993), Gatti et al (2020)). What is meant by a niche in a complex system is an opportunity for gain through the application of a set of connective rules that can be technological, organisational or operational, or some combination. However, there is a key difference between biological and economic self-organisation. With the former, niches tend to be exogenously available as exploitable connections between existing elements in complex systems. With the latter, new connective structures can be created endogenously to attain new aspirational goals in uncertainty (Shackle (1972)). So, knowledge gradients are not exogenously given, they are created, opening up new market niches. Typically, a business that fully occupies an existing market niche has the power to eliminate product or process variations that are viewed as a threat. This defence against mutations is also observed in biology. In economic systems, even when there is deliberate choice and preparatory research is conducted, we observe many, seemingly foolish, attempts by entrepreneurs to enter already full market niches. But this need not be irrational. An entrepreneur can imagine that she is actually entering a new market niche, that the niche is not full, but growing, or that production costs can be under-cut, under-estimating the economies of scale mountain that has to be climbed to be price competitive with existing dominant players, even if they are inefficient. Knowledge problems abound in uncertainty. So, be it in a biological or economic context, for a mutation to develop and survive, it must find a new niche, or a segment of an existing full niche that is open because it is of marginal interest to the dominant player(s) because of its low profitability. So it is not competition that results in the emergence of variety, it is the *avoidance*, intentional or otherwise, of competition (Ulanowicz (2009)).

In an open market niche, an entrepreneur seeks cooperation. She has to create an economic organisation as a cooperative network structure in which there is specialist diversity of function. And external network connections are forged via contracts. In an open market niche, this is a story of cooperation, both within a growing entity and with other players. Growth is fundamentally important because it is static and dynamic economies of scale and scope that are decisive and these can be achieved by merger and cooperative agreements. At the same time, the spread of adoption of the relevant new rule (or rule set) creates a meso-rule and results in external economies of scale. There is a great deal of evidence in the business literature of such processes in open market niches (Malerba (2006), Klepper and Malerba (2010)). So economic evolution, and associated growth, involves both quantitative and qualitative changes that are both creative and cooperative. Both are vitally important. Increasing scale yields reductions in unit costs and qualitative change yields improvements in product quality and/or productive efficiency. Both involve creativity of some kind with incremental innovations in production and marketing via experimentation and the application of skills and knowledge acquired elsewhere. Of course, luck also plays a role but it is just an 'error term' in an otherwise non-random process.

Luck (randomness) is not a primary driver of economic evolution, even though improvements in products and processes involve much tinkering rather than planning. All such tinkering is not random because it is goal related (or teleological) and it still involves experimentation based upon existing non-random skills and knowledge (Ferrer-Cancho et al (2003)). There is an accumulation of modifications, built upon previous modifications, directed towards a goal. So it cannot be an optimal path to an optimal outcome. Neither is it the other extreme, just competitive selection at work in the face of randomness. What matters is scale. Fully in line with the Price Equation, the entrant that grows fastest will tend to dominate and, when a market niche is full, it is the scale of the incumbent that deters entry, not the intrinsic quality of process or product. And static and dynamic economies of scale are facilitated by specialisation, as Adam Smith (1776) pointed out long ago in his pin factory example. But as soon as we concede that scale is critical (Arthur (1994), Young (1928), Knudsen et al (2017), Lipsey (2018)), we find that cooperation, collaboration and complementary interactions are viable processes to achieve, and share, the fruits of scale economies. And this was understood even by early neoclassical economists, such as Alfred Marshall, who noted that economies of scale would mean cooperative mergers and knowledge sharing would occur to get to a dominant situation.

Now, in the process of entering a new market niche with a new rule set, competition should not play much of a role initially because the niche is mostly empty. Creativity and cooperation should be the primary drivers. And humans are unusually good at both (Bregman (2020), Hare and Woods (2020)). As the market niche fills up, competition should begin to play a more important role. But, even in full market niches, we know that it is often the case that oligopolists engage in implicit and explicit strategic cooperation in price setting and erecting barriers to entry. So, again, collective avoidance of competition is often the priority. This is not in the Darwinian playbook. However, should the market niche shrink for some exogenous reason, we can expect an eruption of battles for survival of the kind that Schumpeter discussed, not the smooth diffusion processes that we observe in growth phases. Who wins will be very historically contingent and subject to fitness in conflict, not the relative fitness of products and/or processes.

Let us consider entrepreneurial entry into a new market niche, or part of a niche that the existing players have neglected or abandoned because it is uneconomic. Scale of production starts small but, as it increases, unit costs fall and qualitative change in the product and/or the production and marketing processes, also takes place. Expansion in demand is, initially, financed by spending shifts from products elsewhere in the economy that have started to become obsolete. The emergence of novelty requires there to be a dual of obsolescence somewhere in the economic system that facilitates the transfer of expenditure. So, initially, substitution of spending in an adjacent market niche can be very small and difficult to spot in a growth context. But, as scale increases, qualitative change is also ongoing and economies of scope can result in the creation of a modified product with qualities that make it directly competitive in an adjacent full niche.

For example, Christensen (1997) discussed how, in the USA, small steel mills, with a new set of connective rules for manufacturing steel, entered the low grade steel market that US Steel was not interested in because of cheap imports. Eventually they improved productivity and quality to such an extent that they began to take market share away from US Steel in the higher quality markets. So, innovation in small plant production processes initiated a self-organisation process that, ultimately, led to a severe decline in the market share of US Steel, the dominant player. It was not eliminated, it adapted to become smaller and more specialised in a more efficient steel industry. But it is over-simplistic to see this as natural selection in action. The mutation was not random, it arose from the fact that entrepreneurship and innovation enabled entry into an adjacent open niche which, in turn, enabled further incremental innovations, explicitly designed to challenge the dominant player. But there is no reason why US Steel, which was structurally inert and lacked new knowledge, could not have engaged in merger or takeover to internalise the technological shift and neutralise the market threat.

When a business is established in an adjacent market niche and begins to secure market share because of product development, it cannot easily be eliminated. A common solution is a negotiated merger or takeover so that the increased variety becomes contained within one business. This strategy is often the route to survival for an existing firm that cannot easily adapt its structure to innovate. Whichever, what we see is the emergence of more specialisation, increases in variety, and scale. GD tells us little about this process. It has not occurred due to random variety-generating process but because of the operation of a process involving human imagination, creativity and cooperation. Any shift in market share that is observed because of the emergence of competition is just a feature of economic self-organisation in a particular meso-rule context.

GD cannot tell us about this because its logic is about competition within a defined market niche. And this has always been a problem in biology - variety only emerges in Darwinian natural selection when niches are partitioned. But, with economic self-organisation, the set of market niches is not defined because they are created endogenously and, in addition, more market niches can emerge as products and processes change qualitatively as self-organisation proceeds. If a large number of new market niches open up, these can be complementary, instead of competitive, with existing market niches (Gatti et al (2020). So we can have scenarios where existing players lose market share but are more than compensated by the growth enjoyed through their entrance to emergent sub-niches. So a competitive process in such a case, leads to specialization rather than elimination. There is mutual benefit (Dopfer et al (2016)).

Some new market niches are complementary with existing niches from the start. For example, toll roads were novel in the UK in the 19th Century. This new innovation initially involved higher fares for passengers but this was more than offset by the benefit of quicker and more comfortable services. So, at the time, the emergence of the toll road innovation was entirely complementary with the existing horse and carriage transportation niche. Both could access the expenditure that was transferred from other goods and services of all kinds. Connective infrastructure has been a particularly important innovation that has been complimentary to products in existing market niches (Lipsey and Carlaw (2020)). Complexity theory tells us that increasing connectivity between elements in a network will always increase value (Witt (2017)).

The mobile phone is an example of a novel innovation that has expanded the connective infrastructure. Whereas, innovation diffusion in the product or process space by businesses is an example of micro-self-organisation, this is a macro version that involves mutual benefit (Dopfer et al (2016)). Railways, roads, power grids, telephone networks, the postal service, the internet, etc., are all examples. Although, these innovations took share from existing businesses, to some degree over time, they enhanced many other existing market niches. For example, the internet has rendered letters almost obsolete, but it has had a massive complementary effect on parcel services allowing postal services to survive and even expand. It is another example of emergent specialisation (or variety) and gains in scale and value.

So, economic self-organisation, via the discovery and exploitation of new niches yields new variety via specialisation and scale economies (Saviotti and Pyka (2004)). However, there are some cases where a business in an existing niche is not turned into a specialism but eliminated entirely. This is the opposite of the complementarity case and it is the one that GD relates to most closely. An example is the replacement of horsepower by the combustion engine in the early 20th century. Initially, the application of the combustion engine was only for 'horseless carriages' that were only bought by the rich as expensive leisure goods. Although they did substitute for horsepower in this context, they did not seem a threat to the many industries built around horsepower applications. But, as diffusion got underway, the unit cost of the combustion engine and the products they powered fell and the range of new applications increased. There came a cost point where a range of existing horsepower niches could be entered.

In the US, the personal transportation crossover was probably the Model T Ford. Not only did it offer a novel form of transportation in cities for those who found it not feasible to use horses that had to be fed and stabled, but it also replaced existing horse and carriage combinations and did so quite rapidly in the early 20th Century. In addition to the advantages of dynamic and static economies of scale and scope, the cost of gasoline, relative to pasture and hay, also declined markedly, again because of economies of scale in production, distribution and storage. Being much smaller than a steam engine, applications were devised that substituted also for labour power, just as the horse had done. Some involved entirely new market niches, such as air-travel which, again, did not initially threaten long haul passenger sea travel but eventually eliminated it, apart from cruising.

This case of fossil fuel combustion/horsepower substitution does seem to approximate the GD representation of economic evolution. There was little complementarity between the old and new technologies and the replicator/interactor distinction was approximated with large effects upon existing interactors. Large numbers of people lost their livelihoods with corresponding shortages of skilled labour in operating and servicing combustion engine driven products. This seemed to contribute significantly to the political upheavals and associated cultural shifts in the early 20th Century. Again, we see how the expansion of novelty and obsolescence go hand in hand. And the changes were radical: cities were transformed in scale and complexity and agricultural productivity increased dramatically contributing to massive rural-urban migrations. By the 1950s, in the US, the combustion engine had replaced almost all horsepower applications and opened up many more complementary sub-niches, leaving only very specialised horsepower applications in very rough terrains and leisure activities. Although GD can be enlightening, in a pedagogic sense, when investigating the replacement of certain general purpose technologies (GPTs) (Lipsey et al (2005)), it cannot provide a methodology to track how change actually occurred. Even in the case of the rapid replacement of horsepower by the combustion engine, the opening up of a host of new market sub-niches blurred the competitive dynamics that were clearly operative. And it was not a simple story of replacement and dominance. The very core of the economic system was disturbed, precipitating conflict between vested interests and the ultimate emergence of modified socio-cultural rules to curb such conflict and to facilitate, or suppress, the wide adoption of the new GPT.

GD cannot tell us about the socio-political upheaval and the economic consequences of such a competitive process because it is situation specific. Although what occurred was roughly in line with GD thinking over about a half century, it was actually a process that involved diffusion, obsolescence, expanding and contracting niches which GD has little to tell us about. All GPT transitions involve some degree of socio-political disturbance because they involve winners and losers. The structural commitment that all complex economic systems must have to be sufficiently ordered to function results in political conservatism. And history tells us that such conservatism has sometimes won the day with disastrous consequences (Diamond (2005)). But cooperative adaptation and structural transitions without serious socio-political problems have also been observed.

For example, the mobile phone which is, in fact, a computer, camera, phone and a host of other things has, as yet, tended not to have fatal impacts on the existing market niches that were entered. For example, landlines remain common, cameras and watches have retreated to more specialised niches and notebook computers have not been strongly affected by the advancing computing capability of mobile phones. And the same story applied, self-organisation, starting with a bulky, expensive and unthreatening executive toy, has evolved into a product which has enabled specialisation, increased variety and has opened up many new sub-niches. Neo-Darwinian selection has not been dominant because the mobile phone did not enter a full niche (landlines), but rather, it entered a mobile communications niche that yielded a bewildering expansion of complementary sub-niches. This emergence of novelty has been distinctly non-random. What the mobile phone has done is attract spending, not just from adjacent niches, but from products all across the economic system. So distant trails of obsolescence in spending patterns have diminished sales of established products in unexpected places but, along with other computer related innovations, the mobile phone has increased the efficiency of production on the margin, releasing human resources to be taken up in new sectors, and induced specialisation. So, because of strong complementarities with existing technologies, the process of structural change that has not been as traumatic as was the case with the combustion engine Instead of catastrophic job losses, it has steadily induced labour transfers from, for example, manufacturing to services. Provided that a new GPT permits an old one to survive as a specialist technology, the disruptive effects of change are reduced.

5. The Augmented Logistic Diffusion Methodology

GD is a heuristic that is built upon an ontology that views change as a competitive struggle. Economic self-organisation a heuristic that is built upon a contrasting ontology, that economic change is the result of creativity and cooperation. It is built upon solid scientific foundations: the Second Law of Thermodynamics and the fact that all living systems, including economic systems have to be dissipative structures to survive and develop. Such structures must all access energy gradients, however, humans, do this by accessing knowledge gradients, not just by observing the world around them, but by constructing new knowledge, via the imagination. So, economic self-organisation is the primary driver of economic evolution. Such a heuristic has a solid evidential basis in the vast number of case studies of entrepreneurship and innovation. But a heuristic is only of scientific value if it can be directly connected to an empirical methodology that can address historical data that economic systems generate.

Any dissipative economic structure grows if there is a knowledge gradient to be exploited and growth stops when the gradient has been eliminated and the corresponding niche is full. This is a general tendency in the growth phase of a self-organisational process and exhibits itself in some kind of sigmoid growth path in historical time (Foster (2005b)). This reflects the fact that self-organisation is both self-stabilising and self-amplifying (Foster (2017)). So here we have a general empirical prediction about growth in the presence of self-organisation that can be employed in investigations of the growth of firms, industries and economies. The economic self-organisation heuristic is not grand and philosophical like NET/GET or GD. It is embedded in history and the empirical methodology, employing, for example, the logistic or Gompertz function, can only be fitted growth phases where entrepreneurship is operative and innovation is diffusing, it does not explain anything about the outcomes of the structural transitions that occur when such growth reaches a diffusional limit. That is the terrain of political scientists, historians, anthropologists, etc., investigating highly situation-specific dynamics, not economists. So the economic self-organisation heuristic must always be applied in conjunction with research findings in non-economic disciplines. Complex economic systems are structures of rules and these are supported and altered via non-economic processes.

There are large numbers of studies showing the diffusion of innovation follows a sigmoid growth trajectory over time. Many are found to follow logistic or Gompertz curves. The innovation literature abounds with examples (Rodgers (2003)). Metcalfe (2004) goes so far to argue that this observed tendency is so pervasive that we can consider it a "logistic law". But this methodology is not just for nonlinear curve fitting but one for building models that presume the underlying existence of a logistic process because of self-organisation. So, there need not be a logistic curve observable in the data under consideration. As such, the presumed underlying logistic process must be augmented by a range of relevant variables that are hypothesised to shift the diffusion curve or the limit to which it tends. It is here that competition enters the frame. Price competition is the most common form of competition in economic systems and price information is straightforward to obtain. In Foster (2017) it is shown that there is a special, but very unlikely, case where the growth under examination is only about competition. The logistic process can be impacted by a range of other variables, economic and non-economic, and the significance of these can be tested using, for example, econometric and statistical methods, suitably interpreted (Foster and Wild (1999a, 1999b) and Foster and Potts (2009)).

Although, sigmoid functions have been estimated in a number of studies of growth in various contexts, few have connected with the self-organisational heuristic. Indeed, many are not about economic self-organisation at all, but, instead, describe quite predictable developmental processes. So it is very important that a historical narrative is provided to ensure that a self-organisation process is being dealt with. Empirical examples of the application of the augmented logistic diffusion methodology by this author at sectoral and macroeconomic levels of inquiry are: Foster and Wild (1999a, 1999b), Foster (2014), Foster (2016) and Foster (2020).

Single firm and product studies of innovation using logistic functions have been much more popular in the business strategy and organisational ecology literature but, again, not very often within the context of the self-organisational heuristic. For example, Meade and Islam (2006) show that the logistic has been popular for a long time in marketing, starting with the pioneering study of Bass (1959). Given all this, it is surprising that the pioneering research of Kuznets (1953), Griliches (1957) and Mansfield (1968) in economics, tracking innovation along logistic functions, did not lead to the later adoption of the self-organisational heuristic as the centre-piece of evolutionary economics in growth contexts of the Schumpeterian kind.

GD proponents, who tend to be reluctant to emphasise the importance of endogenous variety generation, might argue that observed diffusion processes are just competitive selection in action leading to dominant features of some kind. But the moment that it is acknowledged that mutation is non-random and that the replicator/interactor distinction rarely holds in economic settings, this cannot be so. Also, when we look at the Price Equation, and the very similar replicator dynamic model, they are mathematical constructions that are not specifically about competition, but about the outcome of differential rates of growth. But this can, equally, come about because of growth in cooperation to increase scale in an open niche, remembering Frank's (1995) acknowledgement that the Price Equation is really just a useful tautology that can be employed in the development of quite different theoretical approaches. And, as already opined in Foster (2005b), the self-organisation heuristic is capable of containing all of strands of evolutionary economics as particular cases, including neo-Austrian representations of 'spontaneous order'.

6. Conclusion

Proponents of the application of GD, such as Hodgson and Knudsen (2010), must be commended for providing a clearly specified neo-Darwinian heuristic for evolutionary economics. Much confusion has been cleared up. However, just as Alfred Marshall rejected the general equilibrium representation of neoclassical economic theory as a generally applicable heuristic in empirical contexts, so GD can be rejected here on similar grounds. There is a lack of connection with an empirically established law and assumptions are adopted that disconnect the heuristic from history. Although it is fully accepted that the Price Equation can represent any evolutionary process, GD is a special case that fits well in biology where variety is largely random and there is a clear distinction between replicators and interactors. So natural selection must dominate in biological evolution. Economic evolution is different. Variety generation is a creative process and there is often no clear distinction between replicators and interactors. Self-organisational processes involve cooperation to fill new niches that are the product on imagination and creativity and, therefore, endogenously determined. And increases in cooperation, for example, in the mutual adoption of meso-rules, means that the definition of 'interactor' keeps changing, as do 'replicators' as incremental innovations and learning from experience changes them qualitatively.

Aldrich et al (2008) argue that: "Even if there is not a fierce life-and-death struggle between rival customs or institutions, some explanation is required of why some enjoy greater longevity than others, why some are imitated more than others, and why some diminish and decline. Any such explanation must come under the general rubric of selection." (P.585). So, for them, all that has been discussed here is just "selection," even though it might involve cooperation in an open niche. This is tautological generality. What Metcalfe (1998) refers to as "restless capitalism" is, in fact, about the emergence of new knowledge gradients - the generation of new structures and activities from imaginings, which are usually in plentiful supply. The notion that these imaginings, or ideas, are naturally selected, as they get taken up in self-organisational processes, is unhelpful. Good ideas spread like wildfire and result in eager cooperation to create new structures. Entry into a new niche involves differential growth and the domination of one or more meso-rule sets, but to see this as natural selection, rather than a process of self-organisation approaching a growth limit, would seem to be a contorted vision of economic evolution.

Of course, there is no denying that competition is important in economic evolution but its impact varies in its strength. As soon we accept that cooperation is important, it is theoretically possible that all 'interactors' adopt the new rule set, leaving the competitive balance unaffected. However, we know that this does not happen because such 'universal cooperation' can never exist in a complex system. Incomplete knowledge and irreversible commitments to existing rule structures are pervasive, preventing universal adaptation and encouraging strategic behaviour. But acknowledgement that there exists cooperation in diffusion processes means that the distinction between replicators and interactors in a complex economic system is misleading because existing interactors can copy new replicators and, in turn, replicators can be improved as interactors adopt them. This is self-organisation in action.

Building a heuristic out of an observed historical tendency operating in complex economic systems is a fundamental departure from the theoretical norms usually adhered to in economics. It implies that, when dealing with economic growth and associated structural change, science has to be done differently. Except in pre-scientific contemplation, a heuristic should be neither based upon abstract, timeless generalisations nor just the inductive examination of data without theoretical direction. This can only be done if the chosen heuristic is directly connected with observed historical tendencies. The self-organisational heuristic connects with a methodology that can be applied in growing contexts. The history that we observe is divided into two distinct categories: phases where structural change unfolds in orderly ways that can be impacted by the kinds of incentives that are focussed upon in conventional economics, and phases where there is structural turbulence and transition where research must involve political scientists, anthropologists, historians, etc. This is because of the key importance of meso-rules in complex economic systems (Blind and Pyka (2014)).

Doing science does not just involve description. Estimating augmented logistic growth models, as opposed to just fitting logistic curves, involves testing hypotheses and prediction, based upon models that are historical in construction. But the dual presence of historical determinism and indeterminism means that growth predictions have to be qualified by the increasing likelihood of structural crisis and transition (Foster and Wild (1999b)). As Maynard Keynes famously observed, forecasting the weather is of little value when the sea is flat. What logistic modelling can do is warn of coming structural inertia and instability. But such modelling does not tell us what policies will be necessary to facilitate transition. These tend to be context specific. Again, we have to look to other disciplines to ascertain which meso rules are blocking change and what kinds of new policy-driven rules can assist a structural transition and protect those damaged by it. So, adoption of the self-organisation heuristic means that economists can only have a limited role in explaining economic evolution and in the development of policies to deal with it. Abstract generalisations, so popular in economics, must be replaced by context specific analysis that is always connected to the findings in other disciplines. Many institutional and evolutionary economists have, over the years, tried to do this and have often been shunned by conventional economists for doing so. Hodgson and Knudsen (2010) recognised this reality, but constructing an alternative abstract heuristic of the 'general' kind was a step in the wrong direction.

References

Aldrich, H.E., G.M. Hodgson, D.L. Hull, T. Knudsen, J. Mokyr and V.J. Vanberg (2008). In Defence of Generalized Darwinism, *Journal of Evolutionary Economics*, 18, 577–596.

Allen, P.M. (2005), 'Understanding Social and Economic Systems as Evolutionary Complex Systems', in K. Dopfer (ed.), *The Evolutionary Foundations of Economics*, Cambridge: Cambridge University Press, pp. 431–458.

Arthur, W. B., (1994). *Increasing Returns and Path Dependence in the Economy*. Ann Arbor: University of Michigan Press

Arthur W.B. (2014) *Complexity Economics*. Oxford: Oxford University Press.

Annila, A. and Salthe, S. (2009), Economies Evolve by Energy Dispersal. *Entropy*, 11, 606-633;

Ariely, D. (2008). *Predictably Irrational*. New York: Harper Collin

Bass, F.M. (1969). A new product growth model for consumer durables, *Management. Science.* 15, 215–227.

Blind, G, Pyka, A. (2014) The rule approach in evolutionary economics: a methodological template for empirical research. *Journal of Evolutionary Economics*, 24(5), 1085–1105

Boulding, K. E., 1981. *Evolutionary Economics*. Beverley Hills: Sage Publications

Bregman, R. (2020) *Humankind: A Hopeful History*. London: Bloomsbury

Buenstorf, G. (2006). How Useful is Generalized Darwinism as a Framework to Study Competition and Industrial Evolution? *Journal of Evolutionary Economics*, 16(5), 511–527.

Christensen, C.M., 1997. *The Innovator's Dilemma; When New Technologies Cause Great Firms to Fail*. Boston: Harvard Business School Press.

Cordes, C. (2006), 'Darwinism in Economics: From Analogy to Continuity', *Journal of Evolutionary Economics*, 15(5), 529–541.

David, P.A. (2007) Path Dependence, its Critics, and the Quest for 'Historical Economics'. In: Geoffrey M. Hodgson (ed.),*The Evolution of Economic Institutions*, Chapter 7, Cheltenham: Edward Elgar.

Diamond, J. (2005). *Collapse: How Societies Choose to Fail or Survive.* London: Allen Lane, Penguin.

Dodgson, M., Hughes, A., Foster, J. and Metcalfe, S. (2011). Systems thinking, market failure, and the development of innovation policy: The case of Australia. *Research Policy*, 40, 1145-1156

Dopfer, K., J. Foster and J. Potts (2004), 'Micro–Meso–Macro', *Journal of Evolutionary Economics*, 14(2), 263–279.

Dopfer, K., Potts, J. and Pyka, A. (2016) Upward and downward complementarity: the meso core of evolutionary growth theory. *Journal of Evolutionary Economics*, 26,753–763.

Ferrer-Cancho, R., Montoya, J.M. and Valverde, S. (2003) "Selection, Tinkering, and Emergence in Complex Networks: Crossing the Land of Tinkering," *Complexity*, 8(1), 20-33.

Foster, J., (1987). Evolutionary Macroeconomics. London: Unwin Hyman (Reproduced in the Routledge Revivals Series, 2011).

Foster, J. (1993). Economics and the self-organisation approach: Alfred Marshall revisited? *The Economic Journal* 103, (419), 975-991.

Foster J (1997) "The analytical foundations of evolutionary economics: From biological analogy to economic self-organization." *Structural Change and Economic Dynamics*, 8, 427–451

Foster, J. (2000). Competitive selection, self-organization and Joseph A. Schumpeter. *Journal of Evolutionary Economics* 10 (3), 311-328.

Foster, J. (2005a). From simplistic to complex adaptive systems in economics. *Cambridge Journal of Economics*, 29, 873-892.

Foster (2005b). The self-organisational perspective on economic evolution: a unifying paradigm. In K. Dopfer (ed.), *The Evolutionary Foundations of Economics*, Cambridge: Cambridge University Press, pp 367-390.

Foster, J. (2011). Energy, aesthetics and knowledge in complex economic systems. *Journal of Economic Behaviour and Organization,* 80, 88–100

Foster, J. (2014) Energy, knowledge and economic growth. *Journal of Evolutionary Economics*, 24(2), 209–238

Foster, J. (2016). The Australian growth miracle: an evolutionary macroeconomic explanation. Cambridge Journal of Economics, 40, 871-894.

Foster J. (2017). Prior commitment and uncertainty in complex economic systems: reinstating history in the core of economic analysis. *Scottish Journal of Political Economy*, 64, 392–418

Foster, J. (2020) The US consumption function: a new perspective. *Journal of Evolutionary Economics*. https://doi.org/10.1007/s00191-020-00711-6

Foster J., Metcalfe J.S. (2012) Economic emergence: An evolutionary economic perspective. *Journal of Economic Behavior & Organization,* Elsevier 82, 420–432

Foster, J. and Potts, J. (2009). A micro-meso-macro perspective on the methodology of evolutionary economics: integrating history, simulation and econometrics. In: Gaffard, J-L, Nesta, L. and Cantner U., *Schumpeterian Perspectives on Innovation, Competition and Growth.* Berlin: Springer/Physica.

Foster, J. and Wild, P., (1999a). Econometric modelling in the presence of evolutionary change. *Cambridge Journal of Economics* 23, 749-770.

Foster J. and Wild P., (1999b). Detecting self-organisational change in economic processes exhibiting logistic growth. *Journal of Evolutionary Economics*, 9, 109-133.

Frank S.A. (1995) George Price's contributions to evolutionary genetics. *Journal of Theoretical Biology* 175, 373–388

Frank, S.A. (1998). *Foundations of Social Evolution* Princeton: Princeton University Press.

Gatti, R.C., Koppl, R., Fath, B.D., Kauffman, S.,Hordijk, W., Ulanowicz, R.E. (2020) On the emergence of ecological and economic niches *Journal of Bioeconomics*, 22, 99–127.

Gillesa, R.P., Lazarovab, E.A. and Ruysca, P.H.M. (2015). Stability in a network economy: The role of institutions. *Journal of Economic Behavior & Organization* 119, 375–399.

Griliches Z (1957) Hybrid corn and the economics of innovation. *Econometrica* 25, 510-522

Hannan, M. T., and Carroll, G.R. (1992*). Dynamics of organizational populations: Density, legitimation, and competition.* Oxford: Oxford University Press.

Hare, B. and Woods, V. (2020), *Survival of the Friendliest*. New York: Penguin Random House.

Hayek, F.A. (1973). *Law, Legislation and Liberty, Vol. 1: Rules and Order*. Chicago: University of Chicago Press

Hodgson GM (2002) "Darwinism in economics: from analogy to ontology." *Journal of Evolutionary Economics*, 12, 259–281

Hodgson, G.M. (2019). *Is There a Future for Heterodox Economics? Institutions, Ideology and a Scientific Community.* Cheltenham: Edward Elgar.

Hodgson, G., & Knudsen, T. (2010). *Darwin's conjecture: The search for general principles of social and economic evolution*. Chicago: University of Chicago Press.

Kauffman, S. A. (1993). *The origins of order: Self-organization and selection in evolution*. Oxford: Oxford University Press.

Kirzner, I. (1997). Entrepreneurial discovery and the competitive market process: An Austrian approach. *Journal of Economic Literature*, 35, 60–85.

Klepper S (1997) Industry life cycles. *Industrial and Corporate Change* 6(1), 145–181

Klepper, S. and Malerba, F. (2010). "Demand, innovation and industrial dynamics: an introduction," *Industrial and Corporate Change,* 19(5), pages 1515-1520.

Knudsen T. (2004). "General selection theory and economic evolution: The Price equation and the replicator/interactor distinction" *Journal of Economic Methodology* 11(2), 147-173.

Knudsen, T., Levinthal, D.A. and Winter, S.G. (2014) Hidden but in plain sight: the role of scale adjustment in industry dynamics. *Strategic Management Journal*, 35 (11), 1569-1584

Kuznets, S. (1953). *Economic Change.* New York: Norton.

Lane, D.A. and R. Maxfield (2005), 'Ontological Uncertainty and Innovation', *Journal of Evolutionary Economics*, 15(1), 3–50.

Lawson (1997.) *Economics and Reality*, London: Routledge.

Lawson (2019) Mathematical modelling in economics: seeking a rationale. Chapter 3 in *Institutions and Evolution of Capitalism: Essays in Honour of Geoffrey M. Hodgson,* Eds. F. Gagliardi and D. Gindis. Cheltenham: Edward Elgar

Levit, G.S. Hossfield, U. and Witt, U. (2011) Can Darwinism be "Generalized" and of what use would this be? *Journal of Evolutionary Economics*, 21, 545-562.

Liagouras, G. (2017) The challenge of Evo-Devo: implications for evolutionary economists. *Journal of Evolutionary Economics,* 27:795–823 DOI 10.1007/s00191-017-0525-5

Lipsey, R. G. (2018) *A Reconsideration of the Theory of Nonlinear Scale Effects: The Sources of Varying Returns to, and Economies of, Scale*, Cambridge Elements, Cambridge, Cambridge University Press.

Lipsey, R. G. and K. I. Carlaw (2020) "Industrial Policies: Common Not Rare", Simon Fraser Economics Department Discussion Paper dp20-11.

Lipsey, R. G., Carlaw, K.I and Bekhar, C.T. (2005). *Economic Transformations: General Purpose Technologies and Long Term Economic Growth*. Oxford University Press.

Malerba, F. (2006), 'Innovation and the Evolution of Industries', *Journal of Evolutionary Economics*, 16(1), 3–23.

Marshall, A. (1890), *Principles of Economics*, Vol. I, London: Macmillan

Mansfield, E., 1968, *Industrial Research and Technological Innovation*, New York: W.W. Norton.

Meade, N., Islam, T. (2006). Modelling and forecasting the diffusion of innovation- a 25-year review, *International Journal of Forecasting,* 22, 519-545

Metcalfe, J.S., 1998. *Evolutionary Economics and Creative Destruction*. London: Routledge.

Metcalfe, J.S. (2004) Mansfield and the diffusion of innovation: an evolutionary connection, *The Journal of Technology Transfer*, 30 (1), 171-181

Mokyr J (1996) Evolution and technological change: a new metaphor for economic history? In: Fox R (ed) *Technological Change*. Harwood, London, pp 63–83.

Nelson, R.R. (2006), 'Evolutionary Social Science and Universal Darwinism', *Journal of Evolutionary Economics*, 16(5), 491–51

Nelson, R. (2016) Behavior and cognition of economic actors in evolutionary economics. *Journal of Evolutionary Economics,* 26, 737–751

Nelson, R. (2020) A perspective on the evolution of evolutionary economics. *Industrial and Corporate Change*, 1–18.

Nelson, R., Winter, S., (1982). *An Evolutionary Theory of Economic Change. Cambridge*, Mass.: Harvard, Belknap Press.

Ostrom, E. (1990*) Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge: Cambridge University Press

Price, G. R. (1970), Selection and covariance*, Nature*, 227, 520–521.

Price, G. R. (1972), Fisher's "fundamental theorem" made clear, *Annals of Human Genetics*, 36, 129–140.

Robert, V., Yoguel, G. and Lerena, O. (20)17. "The ontology of complexity and the neo-Schumpeterian evolutionary theory of economic change," *Journal of Evolutionary Economics*, Springer, vol. 27(4), 761-793.

Rogers, E. (2003). *Diffusion of Innovations*, 5th ed., Free-Press, Simon and Shuster, New York.

Saviotti, P.P. and A. Pyka (2004), 'Economic Development by the Creation of New Sectors'*, Journal of Evolutionary Economics*, 14(1), 1–36.

Scitovsky, T. (1976), *The Joyless Economy: the psychology of human satisfaction*. Oxford: Oxford University Press.

Shackle, G. L. S. (1972). *Epistemics and Economics*. London: Cambridge University Press.

Schumpeter, J. A. (1934). *The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle*, English translation of Schumpeter (1911) by Redvers Opie, Cambridge, Mass.: Harvard University Press.

Schneider, E., Sagan, D., 2005*. Into The Cool: Energy Flow, Thermodynamics and Life*. Chicago: Chicago University Press.

Smith, A. (1776/2000). *The Wealth of Nations.* New York: Modern Library.

Ulanowicz, R. E. (2009). *A third window: Natural life beyond Newton and Darwin*. Conshohocken, PA: Templeton Foundation Press.

Veblen, T. (1898), 'Why is Economics not an Evolutionary Science?' *Quarterly Journal of Economics*, 12(4), 373–397.

Veblen, T. (1914/2006). *The Instinct of Workmanship and the State of the Industrial Arts*, New York: Cosimo Classics.

Vromen, J. (2012) Darwin's conjecture: the search for general principles of social and economic evolution, *Journal of Economic Methodology*, 19 (1), 77-81,

Vromen, J. (2019), 'Generalized Darwinism in Evolutionary Economics: The Devil Is in the Detail', In Witt, U. & Chai, A. (eds.), *Understanding Economic Change – Advances in Evolutionary Economics,* Cambridge: Cambridge University Press, pp. 120-154.

Young, A. A. (1928). Increasing Returns and Economic Progress, *Economic Journal*, 38(152), 527-542.

Winter S. (2014). The future of evolutionary economics: can we break out of the beachhead*? Journal of Institutional Economics,* 10 (4), 613–644

Witt, U. (2004). On the proper interpretation of 'evolution' in economics and its implications for production theory*, Journal of Economic Methodology*, 11 (2), 125-146.

Witt, U. (2008). Ulrich Witt, 2008. "What is specific about evolutionary economics?," *Journal of Evolutionary Economics,* Springer, vol. 18(5), 547-575.

Witt, U. (2017). "Capitalism as a complex adaptive system and its growth*," Journal of Open Innovation: Technology, Market, and Complexity*, MDPI, Open Access Journal, vol. 3(3), 1-15.