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ALFRED MARSHALL, EVOLUTIONARY ECONOMICS AND CLIMATE CHANGE

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Sheila Dow
Department of Economics, University of Victoria
Victoria, B.C., Canada V8W 2Y2

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Abstract

The way in which any topic is analysed in economics depends on methodological approach. The purpose here is to explore the argument that the way in which climate change is addressed depends on how economics is understood to relate to the physical environment and also to the social and ethical environment. This involves an exploration of the formation of knowledge, both in economics and in the economy. Alfred Marshall's evolutionary approach to knowledge formation was central to his approach to economics and to his understanding of economic behaviour. Here we consider the application of Marshall's approach to issues around climate change, through the lens of the subsequent development of evolutionary economics and ecological economics.

Keywords: Alfred Marshall, evolutionary economics, environmental economics, ecological economics

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Author Contact:
Sheila Dow, Dept. of Economics, University of Victoria, P.O. Box 1700, STN CSC, Victoria, B.C., Canada V8W 2Y2; E-mail: sdow@uvic.ca; s.c.dow@stir.ac.uk

Alfred Marshall, Evolutionary Economics and Climate Change[1]

Introduction

It is a tremendous honour to be invited to give the Raffaelli Lecture. I met Professor Raffaelli originally through Professor Brian Loasby, my colleague at the University of Stirling. Tiziano impressed me from the start as the epitome of a scholar and a gentleman, and the legacy of his work on Marshall provides a fine illustration of the power of ideas. While my encounters with Tiziano were too few, I absorbed his evolutionary Marshallian way of thinking through his work, and more directly through Brian, contributing to my own work on methodology.

A core element of this way of thinking is the need to adapt theorising to changes in context, something which applies particularly when applying Marshallian ideas to the 21st century. What follows is an effort to illustrate a Marshallian evolution of ideas by an application to the economics of climate change, a change in context since Marshall's time which has the potential for causing massive structural change. Not only does this discussion reflect Tiziano's approach to methodology, but it also reflects his early active involvement in environmental policy.

The relationship between economics and climate change is fundamental. Economic activity causes climate change which in turn impacts on economic activity, ultimately potentially in a catastrophic way. But how this relationship is understood depends on the approach taken to economics. At one level the chosen approach determines how knowledge about the economy is built and how it is assessed. But it also determines whether, and how, economic relations are understood to be separable from social relations and from ethics, on the one hand, and whether, and how, the economy is understood to be separable from the physical environment on the other.

The purpose here is to explore some of the history of ideas which have built up to the current state of thinking. Given the complexity of the evolution of ideas against an evolving real context, an account which spans centuries will of necessity be broad-brush. We seek to identify broad categories to provide a framework within which individual historical figures and pieces of writing might be located.

In particular we identify two general strands of thought, both of which can be found in different interpretations of Marshall. The broadly neoclassical interpretation underpins the market-oriented approach to the economics of climate change which corresponds roughly to environmental economics. However we will focus more on the other, evolutionary, interpretation of Marshall which Tiziano Raffaelli pursued – the 'new view' of Marshall. This strand of thought, which involves some continuity from the Classical approach, now underpins modern evolutionary economics and the systems approach to climate change of ecological economics. These two interpretations of Marshall correspond to closed-system and open-system thinking respectively Loasby (1991: ch. 1, 2003). The two approaches involve a focus on separation and interdependence, respectively, which is of particular importance in terms of

[1] This paper has benefitted from comments and suggestions from Victoria Chick, Alexander Dow, Peter Earl, John Foster and Clive Spash, as well as from discussion with participants following the presentation of an earlier version at the annual STOREP conference, Rome, October 2020, as the Annual Raffaelli Lecture.

the relations between the natural world, society and the economy. The approach taken therefore matters profoundly for how we address climate change.

History of economic thought on the environment

From the Classics to the Marginal Revolution

The early focus on agriculture of economics in the enlightenment period ensured that the physical environment was embedded in economic thought. While this was most obviously true of the Physiocrats, Hume and Smith focused on how the relationship between man and the physical environment evolved over time. Thus they developed a stages theory to track the transition of economic activity and of institutions from a hunter-gatherer society to grazing to arable production and eventually to manufacturing. The physical environment was also central to their analysis of international trade and development as new lands became caught up in commercial relations, notably with the opening-up of the North American frontier.

There was in addition much discussion of the scope for both positive and negative feedback between economic development and society. While the Marxian strand of thought which arose from Classical economics is conventionally understood to emphasise the material interpretation of history (Salter 1992), Smith and Hume had instead emphasised the interaction between the material, the social and the institutional. There was active debate in the Classical period over the moral and social costs associated with the emergence of commercial society, led by Adam Ferguson (1767).

Classical economics focused on physical production and the physical conditions for its reproduction (Christensen 1987). This focus was pursued in terms of a hierarchy of agriculture and the extraction of raw materials on the one hand and manufacturing on the other. Given technology, manufacturing was dependent on the food and raw materials which sustained labour and capital. Because increasing output required increasing material inputs, a marginal productivity framework was inapplicable: output could not be increased simply by increasing labour or capital alone. But, while manufacturing was thought to observe the laws of mass conservation, agriculture and raw material extraction were understood to be subject to diminishing returns. Economic growth was thus subject to physical limits. But it was judged that these limits could be addressed within the socio-economic-political sphere by overseas exploration and settlement of new lands, by trade in raw materials, by technological advance and by moral suasion (with respect to population growth).

The Classical concern with social ethics carried over into the beginnings of the marginal revolution towards the end of the nineteenth century. Indeed the shift to marginalism was supported by those who sought reform as an alternative to a Marxist acceptance of the inevitability of ever-increasing class conflict. This agenda was thought to be best served by developing economics as a technical subject separated from social/ethical/political considerations. This view was encapsulated in the separation of positive economics from normative economics promoted by Marshall's protégé J N Keynes (1890). Identifying economics solely with theory-as-positive-economics suited the push to mimic the physical

sciences, where the unit of analysis in economics was to be utils rather than any physical unit.[2] The stage was set for the ascendancy of the Walrasian equilibrium approach, even if Walras himself had ultimately been concerned to analyse the process of economic growth (Walker 2009). It was through this Walrasian lens that Marshall's contribution to the marginal revolution was interpreted by many, in what became known as neoclassical economics.

Neoclassical economics

As a move away from the Classical approach, the neoclassical approach which arose from the marginalist revolution directed attention away from production to exchange, from an objective to a subjective notion of value, and from questions of growth to questions of allocation. Market prices established in competitive markets were elevated to pole position. In the process the concept of surplus and its distribution, which had been a core concern of Classical economics, fell by the wayside. Theory turned to focus on choice in terms of the maximisation of utility by households and of profit by firms subject to constraints. Robbins (1932, p. 15) encapsulated this shift by defining economics as being concerned with scarcity. But this was the relative scarcity of static equilibrium rather than the scope for absolute scarcity which had been recognised by the Classical economists (and addressed directly by Malthus in particular). Indeed for neoclassicists, wants were deemed to be infinite. The social-welfare goal therefore was economic growth in the form of the maximisation of production (Caldari 2004, Collard 1999).

As far as the neoclassical production function is concerned, the primary factors of production are labour and capital.[3] In its Solow-model form there is a residual factor in the form of exogenous technical change. The Classical land factor became subsumed in the general notion of 'capital', whereby the principle of gross substitution applies to the different types of capital (see Daly and Morgan 2020, Christensen 1987, Harcourt 1983). While natural and man-made capital were complements in Classical economics, they became substitutes in neoclassical economics. Implicitly, natural capital was a free good.

Schabas (2005) documents this 'denaturalization' of economics as applying not only to the role and nature of production but also to the role and nature of the human agent. As she puts it,

> Classical economists took the economy to be a natural entity and saw *homo economicus* as a creature of animal passions and instincts bent on outcomes such as excess population and the dreaded stationary state that were at odds with the dictates of reason. Subsequent economists, such as Mill and the early neoclassicists, took man out of nature. The economy was seen as a result of rational agency, and thus, no longer directly governed by natural forces (Schabas 2005: 150).

This is not to say that concern over limited physical resources was absent from the marginal revolution itself. Jevons (1865) in particular was concerned about limits to coal supplies and the implications for future generations. But he did not advocate limits on coal use. Rather he concluded that a by-product of investment which required the exhaustion of coal stocks would be increased capital in other forms (especially human capital) which would compensate future

[2] Mirowski (1989) portrays the influences which operated in both directions between economics and physics.

[3] The standard framework excludes Marshall's additional organisation-and-entrepreneurship factor of production.

generations and provide the basis for new sources of wealth. Jevons's most lasting contribution to modern thinking on the environment is the 'Jevons paradox', whereby measures designed to increase the efficiency of resource use actually encourage increased demand, exacerbating resource depletion.

Pigou (1920) pursued Jevons's line of enquiry further within his neoclassical welfare framework. Like Marshall, Pigou shared Jevons's view that the welfare of future generations should not be discounted (Collard 1996). Pigou contributed to the neoclassical interpretation of Marshall's marginalist analysis by the way in which he built on Marshall's concept of external economies and diseconomies (Spash forthcoming). Marshall had focused on the external economies which arose particularly in terms of knowledge sharing and creation due to agglomerations in particular sectors (as in industrial districts) - an important dynamic contributor to economic development. Pigou extended the enquiry to include what came to be analysed as externalities. These are (positive or negative) consequences of market decisions which are not themselves marketed, such as the depletion of coal stocks or pollution, but which were more amenable to quantified mechanistic analysis.[4] More generally, while Pigou approached taxation in relation to market pricing, Caldari and Mesini (2011) point out that Marshall's approach to taxation of land was aimed rather at preserving the positive external economies of public goods (green spaces) in the interests of promoting the well-being of the poor.

Although it was then neglected for some time, the concept of externalities became a core idea as environmental concerns later moved up the agenda (Medema 2017). For the neoclassical framework which relied on decision-making in competitive markets to generate social optima, externalities would normally require intervention in the form of subsidies or taxes, respectively, to correct market failure. Thus for example a solution to the Jevons paradox was to offset efficiency gains in resource-based industries with a countervailing tax. In the meantime, Hotelling (1931) contributed further to the incorporation of natural resources into welfare analysis by setting up a framework for analysing the optimal rate of resource depletion. In line with the emerging neoclassical approach, reliance was put on market signals to determine the pace of resource depletion, although the analysis diverted attention from the externalities of resource use.

In the second half of the 20th century a more systemic focus on physical resources emerged, raising questions as to whether particular resources, such as coal, should be used at all. Attention was drawn to the physical limits to growth – the problem of absolute scarcity – by a series of reports such as Meadows *et al*. (1972). But it was several decades before it became accepted more widely that attention needed to be paid to the physical environment and increasingly to the growing threat of climate change. Environmental policy proposals met with some resistance, given the conventional dualistic separation of the economic world from the natural world in a neoclassical framework. Since from that perspective markets are presumed to generate optimal social welfare (measured by GDP growth), any measures to alter market incentives for environmental reasons are presumed to reduce social welfare (Scrieciu 2015).

In any case the neoclassical focus on the power of market incentives had diverted attention away from environmental concerns by encouraging confidence in the scope for technological

[4] See Davidson and Spong (2010) and Caldari and Masini (2011) on the differences between the Marshallian and Pigovian approaches to externalities and their implications for industrial policy.

change to reduce those constraints. But using neoclassical theory to support reliance on markets to induce general technological change through innovation is hampered by the conventional assumption that all present and future information is known, or knowable awaiting discovery (contrasting with Marshall's evolutionary theory of knowledge). This meant that it was difficult for neoclassical theory to develop a satisfactory account of innovation other than treating it as a black box.

In the meantime the emerging field of environmental economics departed from the standard neoclassical model in that natural capital was no longer regarded as a free good (Spash 1995). But the neoclassical interpretation of environmental problems in terms of market failure continued. Environmental economists argued that market forces were being impeded by the fact that the environmental impact of economic activity was not being valued properly. Markets had failed to price in limits to the supply of resources and had not induced enough technical change. Environmental economists therefore sought to establish appropriate values (see e.g. Pearce 2002). This applied not only to resource depletion, but also to the amenity value of conserved natural resources – a (non-marketed) positive externality of the environment.[5] Further, to the extent that there were negative externalities of economic growth which were not priced into business decisions, it was concluded that the state should intervene so that externalities were internalised. Thus for example measures like Pigovian taxes were required to discourage pollution with its social costs, or subsidies were required to encourage innovation in energy-saving technology with its social benefits.

While negative externalities are feedback effects of growth, climate change raises the problem to a whole new level. Not only might growth bump up against natural resource limits, but by causing climate change it actually makes those limits more severe. Given concern that technical change is not occurring rapidly enough, the market-oriented response is still to conclude that climate change has not been priced properly into market decisions. Central banks have encouraged a ramping up of efforts to incorporate climate risk into financial instruments and thus into the provision of finance for climate-related innovation. For example Paulson (2020) suggests that '[w]e need a new asset class of healthy soils and pollinators: Valuing nature as we do traditional goods and services will help us face 21st-century environmental risks'. In fact putting a cost on the risks associated with climate change is seen as an effective rhetorical device to encourage policy action (see e.g. Chami *et al*. 2019).

But, *pace* Jevons, Marshall and Pigou, such efforts still face two types of stumbling block. First pricing natural assets (or indeed any asset) requires the absence of fundamental uncertainty as well as the capacity to monetise all values. Both have been challenged. It is central to the Keynesian critique of quantifying risk in financial markets that predictability of economic outcomes themselves are limited by fundamental uncertainty. But this uncertainty is compounded when considering interrelated systems in the economic, social and physical spheres. Further, limitations on quantification itself, a particular concern of Marshall, posed issues for the assessment of social costs (Kapp 1950).

The second stumbling block refers to the conventional approach to discounting (Pearce 1987). As long as the discount rate is positive, the long-run negative feedbacks from growth

[5] See Ropke (2004, pp. 299-300) and Banzhaf (2019) on the emergence of different strands within the field of environmental economics.

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increasingly lose their significance the further ahead they are. Action on climate change can only therefore be justified by a very low discount rate (privileging future generations) and/or infinite costs (the complete destruction of the planet). This takes the discussion back into social ethics which have been entering more into market discourse. Market pressure is now being put on companies to pursue environmental (as well as social and governance - ESG) goals rather than narrow profit maximisation. A new set of ESG instruments has thus evolved in response to demand, with an institutional structure being developed to establish standards. Such considerations as these are beyond the scope of the conventional market-based neoclassical framework which purports to be positive, detached from ethics. We need to consider alternative approaches which encompass social ethics. Indeed the urgency posed by the current array of crises (including the financial crisis) has been drawing attention more widely to approaches which are not limited to conventional market solutions.

Marshall's evolutionary approach

Marshall is best known within economics for the technical innovations incorporated in the neoclassical interpretation of his work (Raffaelli 2003, p. 139). Indeed the 'abstractions' that Marshall pursued, particularly in Book V of the *Principles*, provided valuable technical inputs into the price-theoretic neoclassical approach to the analysis of welfare. But he also inspired a quite different, evolutionary, approach which now represents the 'new view' of Marshall, as encapsulated in Raffaelli (2003). This interpretation goes beyond previous concerns over the contradictions between the mechanistic and evolutionary aspects of Marshall's work in order to present a more cohesive evolutionary account which downplays the mechanistic analysis (see e.g. Hart 2012).

While Raffaelli (2003) explores the many ways in which Marshall departed from the Classical approach, his approach did reflect some Classical roots (Christensen 1987). The Classical legacy of integrating the natural, social and economic worlds is evident, in Marshall's materialism, as expressed in his definition of economics as

> a study of mankind in the ordinary business of life; it examines that part of individual and social action which is most closely connected with the attainment and with the use of the material requisites of wellbeing (Marshall 1890: 1).

It was also evident in his theorising (Marshall 1890: Book IV) and in his concern with the socio-economic implications of the built environment (Caldari 2004, Caldari and Masini 2011). Further Marshall approached economics, from the Classical perspective, as a moral science (Caldari, Dardi and Medema 2020). Human wellbeing had ethical and political, as well as economic, dimensions. Thus, in addition to the contributions to economic progress from industrial and labour efficiency, human capability and creativity, Marshall like the Classics was concerned with the moral improvement required to make proper use of that progress.

Classical economics had already drawn on ideas of evolution in the physical realm ever since the enlightenment (Schabas 2005: ch. 6). But the nature and role of the concept of evolution in economic thought are open to a range of interpretations. Further the sense in which, and the extent to which, Marshall adopted an evolutionary approach are contested questions (Caldari 2004: 32). Following an outline of the variety of stands of thought within evolutionary economics, Dopfer and Potts (2008: ch. 1) conclude that the common factor is

a rejection of a mechanistic understanding of the economy. This seems to fit with Marshall's ontology, while leaving open the issue of his use of mechanistic analysis.

Here we will focus on the interpretive strand which follows Tiziano Raffaelli's understanding of Marshall's evolutionary approach. Raffaelli (2003) traces Marshall's evolutionary thought to his early work on psychology (notably in his paper 'Ye Machine' where he pursued the possibility of a multi-layered mechanistic account). Marshall delved deeply into the evolution of the mind, 'an evolving self-organization, a system of subsystems, growing with experience but always characterized by its unique asset of routines' (*ibid*.: 35). His characterisation of the workings of the mind was to feature in his wider application of evolutionary thought.

Raffaelli (*ibid*.) notes here the influence of Darwin:

> Natural selection marks out successful routines for repetition, chance variation and foresight explore new pathways when routines fail. Successful trials, if repeatedly called forth, become routine. Together, these two elements account for the evolution of complex systems, which react to external stimuli according to their own internal structure.

Marshall thus came to economics with an evolutionary theory of mind which conflicted starkly with the fixity of rational economic man.

Raffaelli explores how Marshall applied this approach to industrial organisations: 'He constantly scrutinizes how technological, organizational and social change is influenced by human knowledge, activities and (above all) creativity and vice versa' (*ibid*.: 141). His evolutionary model depicted 'a dialectical succession of continuous and discontinuous movements' (*ibid*.; 139).[6] Marshall thus took a systems approach, at both the ontological and epistemological levels. He understood real processes in terms of systems, and also put forward his own system of thought. In this way he echoed Adam Smith's evolutionary systems approach (Skinner 1996), a parallel explored by Raffaelli (Caldari, Dardi and Medema, 2020). He also shared Smith's (1759: IV.1.11) aversion to a rationalist focus on abstract systems: 'a certain spirit of system … [and] … a certain love of art and contrivance … [such that] … we sometimes seem to value the means more than the end'. In the modern literature, this difference is put as the rejection of a closed-system approach in favour of an open-system approach (Loasby 2003, Chick and Dow 2005).

Accordingly, for Marshall, equilibrium included not only an abstract notion central to the neoclassical strand of Marshallian thought, but also a state of order in real time which was the outcome of successful coordination of knowledge and economic activities (Loasby 1991: 16). While neoclassical economics developed around the core concept of static market equilibrium induced by the price mechanism, the evolutionary interpretation of Marshall's concept of equilibrium was quite different, referring to states of economic, social and political order, based on established successful routines (Caldari 2015). Even Marshall's formal partial equilibrium analysis is reinterpreted within an evolutionary framework, whereby it is seen as focusing on

[6] Yet the fact that humans are characterised by 'self-reliance, independence, deliberate choice and forethought' (Marshall 1920: 5) limits the applicability of Darwin's biological model of evolution.

parts of the economy where routines have been disrupted, abstracting from other areas of order with continuing routines (Dardi 2003).

The motivation for Marshall's analysis called for this evolutionary notion of equilibrium. He departed from the neoclassical focus on maximising behaviour and economic growth, focusing instead on the pursuit of the broader economic development, or 'progress' (Loasby 1991: ch. 1) - and indeed sustainable development (Caldari 2004) - as evolutionary processes.[7]

> The particular relation between equilibrium and evolution which characterises Marshall's approach allows us to better understand the balanced interplay between order and process, two categories that, in Marshall, pervade every aspect of society considered as a highly complex body (Caldari 2015: 1071).

It was the evolutionary nature of process that made this interpretation of Marshall's approach incompatible with the neoclassical strand of interpretation. While a satisfactory theory of innovation has eluded neoclassical economics, a theory of innovation as endogenous to economic processes is central to the evolutionary approach (see e.g. Loasby 199: ch. 6 and Freeman 2008). According to this approach, innovation is the response of the creative mind to external stimuli, disrupting routines which had hitherto been selected as successful. It requires an organisational context (within firms, sectors and including the public sector) which supports creativity rather than an undue focus on routine.

We now proceed to explore how an alternative approach based on this evolutionary interpretation of Marshall accords with the evolutionary, systems-based analyses of climate change offered by ecological economics (Daly and Morgan 2020, Halkos 2011).

Evolutionary economics and climate change

While it was not a particular focus for him, Marshall (1890: Book IV) was well aware of the issue of resource depletion. As Caldari (2004) documents, Marshall was also aware of the delicate relationship between humans and the environment whereby human activity can impact on the environment and thus on the extent to which economic development can be sustained. So that this impact would not unduly disadvantage future generations, Marshall believed that the discount rate should be zero. Marshall thus understood the social and the physical as interconnected elements of an evolving system, mediated through the evolution of knowledge and organisation. Further he took an ethical stance on how physical limits should be addressed.

He could not have anticipated the compounding problem of climate change. But he would have been alert to the scope for new contexts requiring an evolution of analysis. In fact, alongside the emergence of environmental economics has arisen an alternative approach which accords

[7] Marshall's focus on the firm meant that he had a particular interest in studying the strategies which would ensure the long-term survival of the firm, i.e. the entrepreneur as the custodian of the firm, just like the farmer as custodian of the land.

more with Marshall's evolutionary approach: ecological economics. But, while Christensen (1987) acknowledges Marshall's Classical roots, he makes no connection between Marshall and ecological economics. Here in contrast we explore the common ground between the two.[8]

Ecological economics treats the economy (and society more generally) and the climate (and the physical environment more generally) as inter-related parts of an overall system. The physical environment is understood as an ecosystem such that the focus is on sustaining the system rather than the availability of any particular valuable resource. As Daly puts it:

> The key to understanding ecological economics is its pre-analytic vision of the economy as an open subsystem of a larger ecosystem that is finite, non-growing, and materially closed (though open with respect to solar energy) (Daly and Morgan 2020, p. 138).

Since the system is open (and complex), expected outcomes are not amenable to quantitative probabilities; expectations are subject to fundamental uncertainty. This means that climate risk cannot be captured in probability distributions. Further, the emphasis on system focuses attention on the scope for unintended consequences of policy action.[9]

As is the case for Marshall, ecological economists focus on economic development as a much broader (and not altogether quantifiable) entity than economic growth, incorporating moral judgements. The principles applied to the goal of development, as articulated by Daly (Daly and Morgan 2020) are that it should be of a sustainable scale (echoing Marshall's 'order'), that distribution be just, and that allocation be efficient. Ethics are central, regarding distributive justice within and between generations (Spash 1995). The focus on development rather than growth also requires an interdisciplinary approach in order to explore the sociology and politics underpinning the policy framework. This is another factor in common with Marshall; of particular import is the reliance of both on the physical sciences.

The aim of steady-state sustainable development (according with Marshall's concept of order in an evolutionary process) involves an explicit departure from the neoclassical assumption that individuals seek to maximise consumption (and minimise work) (Schumacher 1973: ch. 4). Further if the natural and social worlds are understood to be organically interconnected then, not only does climate change affect the economy and vice versa, but the relationships are embedded within social, political and institutional structures. Within an open-system approach the economy and the environment are not separated dualistically; growth and the environment are not mutually-exclusive, but rather interact.

Heterodox economics has sometimes struggled to engage with ecological economics, although methodologically it seems to be more compatible than the more neoclassical approach of environmental economics (Christensen 1987). Spash (2012) and Chester and Paton (2013)

[8] See van den Bergh (2001) on the distinctions between ecological economics and environmental economics; see also Ropke (2004).

[9] Thus for example geoengineering methods are being explored which could reduce the effect of exposure of the mouths of glaciers to warmer sea water. Yet this would in turn affect sea life and the economy of communities which depend on it for their livelihood (Wolovick and Moore 2018).

explore the potential for integration with a range of heterodox approaches.[10] Here we focus on the commonalities between ecological economics and the modern evolutionary approach, particularly on account of its close connections with the work of Marshall. Modern evolutionary economics in the tradition of Nelson and Winter's (1982) analysis of routines focuses on the Darwinian notion of competitive selection. But another strand accords more with the systems approach of ecological economics by seeing competition rather as just one part of the process of self-organisation in complex adaptive economic systems (Foster 1993).

In Marshallian terms, such systems require a suitable system of economic theorising, according to which:

> constrained optimization is practised when it is feasible but this was always seen as being subject to historical constraints and boundaries placed on knowledge and action by the social, cultural and legal rules that prevailed. In other words, economic behaviour is always subject to historical contingency, individual and collective knowledge and the institutional fabric (Foster 2011, pp. 8-9).

Setting out the systems-oriented evolutionary approach, Foster (*ibid*., p. 11) explains the unsuitability of standard neoclassical methods in the following Marshallian terms:

> A fundamental characteristic of [complex adaptive] systems is that they exhibit a degree of structural irreversibility, rendering mathematical analysis that presumes reversibility invalid. Structural irreversibility is associated with 'order' in a complex structure, providing essential continuity over time.

The irreversibility of real processes due to entropy is central to ecological economics (drawing on Georgescu-Roegen 1971). From a theoretical perspective, once the physical system is no longer isolated from the economic system and no longer treated as the supplier of free goods, the reversibility inherent to general equilibrium models is seen to conflict with the second law of thermodynamics. More generally, an inevitable increase in entropy acts against any possibility of an economy settling back into general equilibrium (Pearce 1987). The entropy of an isolated system can never decrease over time and is constant if and only if all processes are reversible. Recycling and renewable energy can serve to limit entropy, but cannot eliminate it, such that economic activity inevitably increases it, making reversibility impossible. It is therefore important from an ecological perspective that growth of economic activity be limited relative to pursuit of well-being from other sources and that any such activity be efficient in minimising entropy.

According to Georgescu-Roegen (1971), production technology consists of materials, energy and know-how, as well as the physical capital and organisational structures (i.e. the embodied know-how) that process them (Christensen 1987, p. 84). Indeed, for evolutionary economists, any policy response needs to take on board the role of institutions in their broadest sense (encompassing customs, norms, routines, laws and so on). These institutions operate at the meso level (between the macro and micro levels) to govern and facilitate economic processes (Dopfer and Potts 2008). Similarly, know-how on the part of firms and households, as well as experts advising on policy, is central to the evolutionary path of institutions. This knowledge itself evolves by means of routines and innovations. Thus for example constraints by the public

[10] See Fontana and Sawyer (2016) and Rezai, Taylor and Foley (2018) for examples of incorporating the physical environment in Post-Keynesian macro models. See also Pressman, Holt and Spash (ed) (2009).

sector on household waste collection are initially disruptive but then lead to stable recycling routines as the norm.

While successful meso-rules bring about coordinated order, the openness of the ecosystem allows for creative introduction of new meso-rules which may or may not be successful at promoting order. Lavoie (2014: ch. 1) explains that institutions perform a stabilising role in terms of addressing a series of paradoxes between the macro and micro levels. For example, he lists the 'paradox of liquidity' (Dow 1987), which contributes to Minsky's 'paradox of tranquillity' according to which stability creates instability in financial markets. The apparently successful coordination of a sustained market boom, fuelled by financial innovation, carries the seeds of its own destruction. Minsky's policy conclusions refer to dynamic regulation in relation to evolving financial structures, i.e. the meso level (Kregel 2014).

While evolutionary economics has focused, in Marshallian fashion, on the human mind and the structures within which knowledge evolves, Foster (2011) advocates a parallel focus on energetics and dissipative physical structures as a way of thinking about the economy as a dissipative structure. In other words the economy can be understood as an open complex system which can self-organise to maintain a steady state short of the system death of a thermodynamic equilibrium. According to the latter outcome, there is an ecological paradox in pursuing economic growth in that the process carries the entropic seeds of its own destruction. The implication is that the drive for growth within capitalism, if unchecked, will destroy it. Addressing the paradox requires attention to the design of meso-rules to govern the relations between the economy and the environment. This approach departs from the neoclassical optimisation framework; policy to address ecological problems, notably those posed by climate change, needs to look beyond solutions in the form of market incentives and penalties to a strategic restructuring of behaviour and institutions away from the goal of economic growth.

While an ecological approach to climate change policy may well include pricing measures in common with the neoclassical approach, more emphasis is placed on non-market measures such as quantity limitations to alter the composition of growth to favour green activities and energy sources (see e.g. Earl and Wakeley 2009). But particularly when shifting away from pursuit of economic growth, the motivation, formulation and mode of introduction of policies needs to be different. The motivation for any policy reflects a particular set of ethics. But there are important ethical issues beyond degrowth. For example there is a particular ethical issue regarding the relative responsibilities of developed and developing countries (as well as different generations). There is also an ethical issue regarding the protection of indigenous communities, particularly those with a long history of successful resource conservation which now face resource exploitation.

There are also substantial political issues to be addressed. The implementation of policy to address climate change by means of radical changes in goals, institutions and behaviours needs to be consensual if it is to be effective. As Raffaelli (1993: 897) put it:

> The environmentalist movement (…) has often, out of necessity, taken the role of the prince's counselor, sometimes forgetting that only that which establishes roots in the culture of a people is going to last.

Finally the possibilities for responding to policy by reducing carbon emissions depends, not only on new social institutions, but also on innovation in alternative technologies; as in other sectors this requires a public-private structure which facilitates and supports innovation. We

are back with Marshall's evolutionary theory of the mind and the central role of the evolution of knowledge. Foster (2011) applies a systemic perspective to the bi-causality of energy and knowledge:

> Energy flow is mediated by the design and use of extractive, transformational, distributional and utilisation systems. All these involve the accumulation and use of knowledge which, in turn, requires the use of human and non-human energy. The technological and organisational meso-rules embodied in these knowledge-energy systems both facilitate and constrain economic growth in a fundamental way. Once such a system is in place, it is difficult to change without a radical shift in core meso-rules. Currently, this can be seen clearly in the case of attempts to shift from coal-fired power generation to non-carbon emitting systems (Foster 2011: 18).

So policy design and presentation need to reflect the sociological, political, institutional and technological context, as well as seek to transform it. In particular markets are understood within ecological economics as social institutions which only account for a portion of socio-economic activity. In any case, if individuals and business leaders are not purely calculative or rational in the narrow neoclassical sense then their response to any attempt to use the pricing mechanism to incentivise behaviour will not have the result predicted by neoclassical theory. Indeed del Valle Erkiaga and Ikazuriaga (2015) explain that the neoclassically-inspired application of a worldwide price mechanism to greenhouse gas emissions proved to be unworkable as the result of institutional failures.

It has been argued here that the two approaches to policy-making (market-focused and evolutionary) accord with the two interpretations of Marshall which we have followed here. Marshall himself discussed the contributions of each approach (Raffaelli 2003: 878-88). Arguably J N Keynes's (1890) account of the scope and method of political economy also attempted to reconcile them. He distinguished between the science of positive 'economics', made normative by the application of values by policy-makers, and the art of 'applied economics' which intermediates between the two.[11] Colander (2002) revived attention to this classification, arguing that applied economics required a different methodology from the prior independent development of theory. Colander (*ibid*.: 197) portrays the methodology of applied economics as follows: 'the art of economics is contextual and as much dependent on non-economic political, social, institutional, and historical judgments as it is on economics'. But for Colander the mainstream methodological approach to *theorising* remains intact; the interaction between the two methodologies remains unresolved.

There has been a steady shift in mainstream economics over the last few decades from theory to applied economics (Backhouse and Cherrier 2017), although inevitably some theory or another still shadows application. Arguably there has been a particular shift in the economics of climate change due to the evident urgency of the problem to be addressed. Indeed Barbier (2020) identifies a shifting focus in environmental economics in the 21st century towards the ecological style of thinking in terms of eco-systems and a broadening of the policy canvas. But for ecological economists a problem remains where recourse is made (implicitly or explicitly) to a theoretical framework which focuses on maximising economic growth through the price mechanism.

[11] See Raffaelli (2003: 97) on Marshall's views on distinguishing (but not separating) the positive from the normative.

A crisis is an extreme form of external stimulus which challenges routinised thought about complex systems, bringing about scientific revolutions in Kuhnian (1962) terms. While financial, economic and health crises are generally more immediate challenges than climate change, the increasing incidence of devastating disasters (forest fires, flooding etc.) is making the climate crisis ever-more immediate. A creative response in individual behaviour, as with industrial innovation, has proved insufficient, in terms of the strength of the stimulus and the capacity for a creative response. From a Marshallian perspective what is required is a change in meso rules to guide behaviour and facilitate creativity. Thus for example planning rules can restrict building on floodplains and governments can restrict future sales of petrol-fuelled cars. Further the public structures which have routinely underpinned industrial innovation can be pivoted to prioritise innovation explicitly addressed to climate change (Mazzucato 2013). For Marshall innovative change should be evolutionary rather than revolutionary: '*natura non facit saltum*' (Raffaelli 2003: 92-3). But the urgency of the climate crisis arguably requires a much stronger stimulus to change.

The policy challenges of climate change therefore require an accommodating application of knowledge, not just among innovators within industry, but also among policy-makers and the experts who advise them. It requires the capacity for creativity which can challenge the routines in thinking which have exacerbated climate change in the past. A closed-system approach to knowledge encourages routine thinking much more than an open-system approach since the latter incorporates the need to adapt to the changing circumstances which make the system open.[12] However open-system thinking, like any knowledge system, is still routinised to some extent, as in the persistence of the dominance of mainstream economic thought. The evolution in thought itself therefore needs more direct attention. Marshall himself is a great exemplar for the evolution of the mind.

Conclusion

Marshall scholarship, as epitomised by Raffaelli's work, is now dominated by an account of Marshall's thinking which is very much at odds with the mainstream textbook representation. Both interpretations have spawned significant bodies of work addressed to the environment, and especially now to climate change. But the difference of approach generates significant differences in terms of theory and policy.

On the one hand, neoclassical economics has applied the technical tools which Marshall developed in his *Principles* to a closed-system price-theoretic analysis focusing on incentives and penalties as a means to correct for market failure. Problems of climate change are seen as negative externalities requiring such correction. The analysis is based on strict separations between the market economy, society/ethics, and natural resources.

The evolutionary understanding of Marshall refers to the serious misgivings he repeatedly expressed about this mechanistic approach to economics. Rather Marshall harks back to the Classical approach with its organic interdependence between the economy, society/ethics and the natural world, as well as its interdisciplinary systems approach. He emphasised order as arising from the successful establishment of routines rather than from an equilibrating price mechanism. At the same time his open-system approach, particularly to knowledge systems,

[12] Good examples of adaptation within an open system are Chick's (1983, 2018) updatings of Keynes's economics.

emphasised the developmental role of innovations which disrupted routines. Economies thus proceed by a dialectical process of order and creativity.

While Marshall himself only occasionally referred to the problem of resource constraints, it has been argued here that his evolutionary approach has much in common with the general approach of ecological economics. There is therefore scope for investigating cross-overs between the two, as explored by Foster (1993, 2011) for example, seeking solutions to climate change by addressing the institutions and routines which govern socio-economic activity at the meso level. Marshall makes a particular contribution to ecological economics discourse by elevating the growth of knowledge to a core position from which to launch efforts to change understandings, organisation and routines, as well as innovations in different arenas.

To conclude where Marshall started, therefore, the exercise in promoting policy to sustain the environment will be most effective if it draws on Marshall's theory of knowledge as being generated by routines and creativity. At one level this theory offers a guide to innovation policy addressed to developing renewable energy, for example. At another level it offers a guide to social innovations whereby attention is addressed to creating what Marshall identified as a favourable social, political and economic atmosphere, as well as to promoting organisational change to promote creativity and also the establishment of new routines (Dow 2014). At yet another level it addresses the question of expert knowledge about an inherently uncertain (because open) process of climate change. Marshall contributes an understanding of how expert social-science knowledge can itself evolve, within society, in order to inform policy.

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