Complexity Economics for Sustainability
Research Seminars series, supported by the ESRC and the Environment Agency

Summary of Seminar 1: University of Oxford, 27-28 November 2008

Introductory lecture: *'Escaping the Last Malthusian Trap: Complex systems, climate change, and economic growth'*
Eric Beinhocker, Senior Fellow, McKinsey Global Institute

Eric Beinhocker explored the implications of complexity economics for the last Malthusian trap - the finite carrying capacity of the planet and in particular our impact on its climate. He noted that, since 1800 AD, a third of the world's population has escaped the old Malthusian traps to achieve high levels of social welfare by harnessing the new technologies and systems of organisation produced by the Industrial Revolution. Another third of the world's population, notably in China and India, are poised to do the same in this Century. However, in order to achieve and spread even wider this prosperity whilst respecting the limits imposed by our impacts on the planet's climate and ecosystems, the world needs to:

- Understand and apply the lessons from the last Industrial Revolution;
- Better understand how to achieve a transition to a low-carbon economy with minimal impacts on welfare and growth;
- Find the points of policy leverage for achieving the necessary 'social engineering' on a massive scale, whilst respecting individuals' free choices.

Mainstream economic theory, which sees the economy as an equilibrium system, is inadequate to address these challenges, as it fails to account for the explosive growth, creation of novelty and spontaneous self-organization of economic systems. In particular, neo-classical economic theory fails in at least four areas:

(1) *Theory of economic growth*:
The Solow theory of growth, based on a production function linking output to changes in capital, knowledge and labour, has been likened by Hermann Daly to "trying to cook with only a kitchen and a chef, but no ingredients".
(2) Cost-benefit analysis (CBA):
Weitzman has argued that, when a system has non-zero probability of catastrophic events that people would pay a lot to avoid, such as extreme climate impacts, then the assumptions underlying cost-benefit analysis no longer hold.
(3) *Accounting for human behaviour*:
Experimental economics has shown that human behaviour in practice does not match that in economic theory, e.g. the use of hyperbolic rather than exponential discounting.
(4) *Time symmetry*:
CBA also fails to account for the path dependence and time irreversibility of climate effects.

Complexity economics views the economy as a 'complex adaptive system', consisting of many agents interacting in a variety of ways, forming coherent social structures, and interacting with their environment, at many levels, covering micro, meso and macro scales. This differs from the standard view in at least five ways:

- *Dynamics*: economies are open, dynamic systems, far from equilibrium;

- *Agents*: made up of heteorogeneous agents, lacking perfect foresight, but able to learn and adapt over time;
- *Networks*: agents interact through various networks;
- *Emergence*: macro patterns emerge from micro behaviours and interactions;
- *Evolution*: evolutionary processes create novelty and growing order and complexity over time.

Complex economic systems use energy inputs to decrease local entropy and create 'fit order', consisting of ordered outputs, plus wastes. Evolution is a search algorithm for creating 'fit order', through processes of variation, selection and amplification. These processes should be understood as a general computation model or algorithm. Building on ideas put forward by Richard Nelson[1], he identified three design spaces that are key in economic evolution:

- *Physical technologies*;
- *Social technologies*, i.e. ways of organising human interactions;
- *Business plans*, i.e. strategies for combining and applying physical and social technologies to achieve economic outputs.

Economic evolution, understood in these terms, is able to explain the explosive non-linear creation of wealth, increasing levels of variety and complexity, and spontaneous self-organization[2]. In order to remain with the limits imposed by the planet's climate systems, an improvement in carbon productivity (GDP/ CO_2e) of 5.6% per year, or ten times by 2050 is needed. This is three times the rate of labour productivity improvement achieved through the Industrial Revolution.

How do we incentivize the evolutionary processes of the economy to achieve these dramatic improvements in carbon productivity:

- Carbon price is necessary, but far from sufficient;
- Innovations in social technologies will be critical, including new regulatory frameworks, new market structures, new business forms and new international institutions;
- Think more broadly than current debates, e.g. female education in developing countries, green technology innovation clusters, catalysing infrastructure investments, and changing cultural norms.

In his response, Sir David King, Director of the new Smith School for Environment and Enterprise at Oxford University, raised a number of issues. He wondered whether 'carbon productivity' is a useful term, or whether we just need to be less 'lazy' about how we use energy. He also wondered whether better economic analysis is really needed to inform climate policy, or whether we should focus on the key role of science and technology in identifying problems and developing solutions. From his experience of advising government, he noted a strategy of avoiding low probability but high impact events would lead to a target of keeping atmospheric concentrations of greenhouse gases below 450 ppm, requiring achieving emissions of 2 tCO_2e per person per annum, or 18 billion tCO_2e per annum globally by 2050.

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[1] Nelson, R (2005), *Technology, Institutions and Economic Growth*, Harvard University Press

[2] Beinhocker, E (2006), *The Origin of Wealth: Evolution, Complexity and the Radical Remaking of Economics*, Random House, London

In response to these comments, Eric Beinhocker argued that economic ideas do shape policy thinking and that carbon productivity is just a useful scorecard. Answering other questions from the audience, he argued that policy-makers need to see how economic growth stories and climate stories interact; that we need to create a new, environmentally sustainable growth model; that we need to understand the role of money as a social technology; that we need to apply a toolbox of quantitative and qualitative methods; and that if the Stern Review had been framed in terms of complexity economics thinking, rather than in terms of cost-benefit analysis, more urgent alarm bells on the scale of the climate challenge might have been sounded.

Session 1 – Complexity and evolutionary approaches
'Complexity, Evolutionary Economics and Environment Policy'
Dr Koen Frenken (Economic Geography Section, University of Utrecht) and Albert Faber (Netherlands Environmental Assessment Agency)

Drawing on their joint work in a paper and edited special issue of *Technological Forecasting and Social Change*[3], Koen Frenken presented an overview of the history of evolutionary and complexity economics. In contrast to neo-classical economics, in which technology, institutions and nature are exogenous, *1st generation evolutionary economics* makes technology endogenous. This began with the work of Joseph Schumpeter in the early part of the 20th Century, who emphasised that capitalism is a system that rewards non-equilibrium behaviour (temporary monopoly rents stemming from innovation). It continued with work analysing the effects of increasing returns to the adoption of technologies, and on technological regimes and sectoral specificities. However, this work generally retained the implicit assumption of a social planner maximizing consumer surplus as in cost-benefit analysis, which is only useful is well-defined and short-run problem contexts. *2nd generation evolutionary economics* (e.g. Chris Freeman, Richard Nelson) also made institutions endogenous and examined their influence on innovation, and the co-evolution of technologies and institutions in driving industrial change. This work has been influential across many disciplines, including development economics, but has so far been poorly formulated in models and also lacks an alternative welfare theory. *Complexity economics* (e.g. Eric Beinhocker) also seeks to make nature endogenous, and emphasizes co-evolutionary processes, compatibility with thermodynamics ("order does not come for free"), and applies the evolutionary algorithm of retention, variety and selection in terms of knowledge as "fit information". This creates the potential for links with other work on ecological economics, and other strands of evolutionary economics (e.g. Saviotti, Witt, Stirling), but gives rise to severe theoretical and methodological challenges.

Finally, he considered the role of government in addressing environmental challenges. He noted that government policy may remain limited as economic growth remains the prime objective, because of the need for tax revenues, and international coordination is weak. The emphasis on national industrial policy is potentially worrying, because of the history of failures and the danger of capture by existing dominant interests, as seems to have happened with the technological transitions concept in the Netherlands. This suggests a key role for social movements in stimulating technological, institutional and environmental change.

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[3] Frenken/Faber (eds.) (2008), "Evolutionary methodologies for analyzing environmental innovations and the implications for environmental policy", *Technological Forecasting and Social Change*

Points raised in response by the audience included: the challenge of theory and modelling when 'everything' is endogenous and the importance of time aspects; the role of users and consumers; the role of institutional inertia; and the need to include the motivations of government, which focus on leadership, short-term issues and looking for win-win-win outcomes. Koen Frenken noted that fast and slow-moving variables can be endogenous to the system; the need to consider intrinsic vs. extrinsic behaviour and the role of learning in behavioural economics; and that modelling is only appropriate when quantitative information is available. Eric Beinhocker argued for the need to be clear about normative and positive aspects in behavioural economics; the importance of design concepts; and the need to ensure an equitable distribution of technology in developing countries, whilst retaining incentives for innovation. Koen Frenken noted the EU has dropped the focus on distribution issues from its environmental policy, and that while there are strong externalities associated with industrial clustering, a critical mass of users is needed to develop a new technology. There is therefore a need to coordinate niches in different countries, bringing in developing countries where there may be fewer institutional barriers to adoption of new technologies.

'Sustainability under pressure: modelling robust strategies for shrinking organisational networks'
Dr Felix Reed-Tsochas (CABDyN Complexity Centre, University of Oxford)

Felix Reed-Tsochas described his recent work on complex adaptive systems, using toy models to understand the interactions between *rule-based behaviour* of agents at the micro level and system properties of *resilience* and *robustness* at the macro level. His focus is on network modelling, and he used a case study of the New York City garment industry to illustrate how methods developed for analysing technological networks can be applied to social networks. This study was interesting as it was a contracting network, with high rates of firm entry and exits at the micro level, but the macroscopic network remained stable for a long period. A simple rule-based model of contraction at the micro level provided an explanation of this robustness under contraction, and a valid prediction of an independent parameter, the 'error rate'.

Discussion
Henry Leveson-Gower (GHK International) began by discussing the application of the ideas in the two papers to policy. He noted that complexity economics seems to be based on common-sense assumptions and so should be the standard way of looking at the environment and innovation, but most of government operates on a neo-classical framework. In relation to network modelling, the challenge is one of communication, through developing useful pictures and concepts, and learning how to tell stories for a wider audience. The more variables there are in the model, the more policy options it can produce, but this can lead to confusing messages. There is a need for more interaction between the modelling and user communities, to produce useful messages for policy-makers. Government is part of the system, but it does not like to be modelled and so is more comfortable with neo-classical models, in which it is outside of the model. The case study suggested that, in the face of industrial decline, institutional links are maintained for a time, which would be good if climate collapse does occur. Economists are getting more interested in network analysis but are networks simply a reframing of a market? Complexity looks at a wider picture than just economic transactions, a wider set of interactions and wider view of relationships.

Jonathan Köhler suggested that a connection between the two talks is transition theory with an emphasis on niches, the requirement for niches to come together in networks, so there is an opportunity to use agent-based network modelling to model niches to explore realistic parameterisation and how such networks grow. Other points raised by the audience included the vulnerability to hubris and exposure to type 2 errors; that relaxing the assumption of costless transactions would lead to too many degrees of freedom for energy modelling; and how to generalise this type of toy model to economic systems. Felix Reed-Tsochas noted that this is not meant to be a global characterisation of a whole system, but is picking up some local characteristics. He argued that it is useful to look for the most minimalist model, with no stochastic elements in the model, and trying to show some sort of generative sufficiency, how macro properties emerge out of micro rules and drawing simple rules to avoid hubris.

Session 2 – Dynamic strategies for sustainability
'The Dynamics of Sustainability: Durability, stability, resilience and robustness'
Prof Andy Stirling (SPRU, University of Sussex)

Andy Stirling explored the concepts of sustainability and resilience, noting that these are adjectives, and so what is to be 'maintained' or to 'rebound' needs to be specified. The conventional approaches to resilience conflate structure (means) and functions (ends), whereas structural resilience can militate against sustainability, through obstructing change to more sustainable systems. Hence, the objects of *sustainability* policy, and of *resilience*, are the Brundtland properties of maintaining environmental integrity, social equity and human wellbeing. Examining the dynamics of resilience, there is a need to differentiate between transient *shocks* and enduring *stresses*, and between situations of *control* (where causes are subject to action within the system) and *response* (where causes are beyond the control of the system), as these relate to different system properties and lead to very different practical policy strategies. These four dynamic sub-properties are claimed to be necessary and sufficient properties of sustainability, addressing multiple conditions of time and action:

	Control	**Response**
Shock	STABILITY	RESILIENCE
Stress	DURABILITY	ROBUSTNESS

Considering power dynamics, incumbent actors and institutions favour maintenance of existing systems and so push for a focus on stability, whereas marginal actors propose more dynamic strategies. This leads to the hypothesis that different strategies, such as addressing vulnerability, legitimacy, adaptability or flexibility of approaches, strategies or institutions, promote different properties within this matrix. A second hypothesis is that a strategy of promoting *diversity* is generally effective in promoting all four properties. Here, diversity may be increased in three different ways: through *variety* (number of elements in the mix), *balance* (evenness in contributions) and *disparity* (degree of differences). In relation to promoting diversity in energy innovation, detailed multicriteria diversity analysis eliciting expert views can reveal the structure of disparities between different energy technologies.

His conclusions were that objects of resilience are *functional qualities*, not structures; resilience is just *one dynamic sub-property* of sustainability; certain strategies promote some properties and not others; and diversity may address all sub-properties.

'Co-evolution of technologies, institutions and business strategies for a low carbon future'

Dr Tim Foxon (Sustainability Research Institute, University of Leeds)

Tim Foxon began by introducing the sources of complexity economics: *evolutionary and institutional economics; ecological economics; behavioural economics; complex systems thinking* and *social shaping of technology*. These contribute to the five properties of economies as complex adaptive systems: *dynamics, agents, networks, emergence* and *evolution*. His focus is on understanding and analysing transition pathways to a low carbon economy. He argued that this requires a co-evolutionary approach, combined with a multi-level framework, addressing interactions between macro, meso and micro levels. This approach draws on insights from three research areas: socio-technical transitions (Kemp, Rotmans, Geels); technological innovation systems (Jacobsson, Bergek, Hekkert); and co-evolution of technologies and institutions (Nelson). *Socio-technical transitions* research covers two main avenues: (1) analysing historical dynamics of transitions using a multi-level perspective, based on interactions between three levels: niches, socio-technical regimes, and landscapes; and (2) transition management as a process of governance, aiming to modulate dynamics of transitions through interactive, iterative processes between networks of stakeholders. *Technological innovation systems* examine the range of actors and interactions (both market and non-market) leading to production, diffusion and use of new, and economically useful, knowledge. This is used to analyse how innovations at micro level, within niches, challenge the dominant regime at meso level. This research examines key functions required for successful innovation, and how these interact through virtuous or vicious cycles. *Co-evolutionary approaches* focus on meso-macro level interactions. For example, how 'carbon lock-in' arises through co-evolution of technologies and institutions, driven by path-dependent increasing returns to adoption (Unruh). Co-evolution is defined here, such that two evolving populations coevolve if and only if they both have a significant causal impact on each other's ability to persist, either by altering selection criteria or changing replicative capacity of individual entities (Murmann). An approach combining insights from these three areas, based on the co-evolution of *technologies, institutions, business strategies* and *user practices*, has roles for both agency and structure in causal influences, and can link issues across macro, meso and micro levels.

This approach may be used to address research and policy challenges at different levels: at the micro-meso level, to inform the mix of policy measures needed to promote the successful innovation and diffusion of low carbon technologies; and, at the meso-macro level, to assess the implications for economic growth of a transition to a low carbon economy. At the micro-meso level, co-evolutionary research has analysed the role of incumbent utilities in the take-up of renewable energy technologies in Germany, Spain and the UK between 1990 and 2005 (Stenzel and Frenzel), and examined innovative business strategies used by sustainability entrepreneurs in the take-up of renewable energy in the U.S. (Parrish and Foxon). New research being pursued by Foxon and colleagues is analysing the interaction of social and technological elements within potential transition pathways to a low carbon energy system for the UK. This is examining pathways with different roles for government, large and small firms, and end users, and different mixes of centralized and distributed electricity generation. The co-evolutionary framework could also assist in the development of more formal, multi-level evolutionary economic models.

Discussion
Prof Christine Oughton (University of Bolzano) began by noting that the incorporation of ideas from co-evolutionary and transitions research brings in governance issues missing from innovation systems literature. Thinking about the car industry, this approach highlights that low carbon technologies are available, but we can't shift, as firms and managers have become locked into specific regimes via behavioural routines. The financial crisis may act as a catalyst for change, with US car manufacturers offering to invest in new technologies in return for a financial bailout. However, further thinking is needed on bounded rationality and the role of shared conventions. Herbert Simon's concept of bounded rationality, focussing on limits to actors' computational powers, neglects real uncertainty, and shared conventions (e.g. give way to the right at a crossroads) may be needed to find mutually beneficial outcomes. The challenge is then how to change these conventions when they are locked-in.

Other points raised by the audience were: Where does adaptation and mitigation fit into Andy's typology? How to define 'system' to avoid privileging members of the current regime? the need to beware of constructing an unfair 'straw man' of neo-classical economics; and What do economists do in relation to diversity that is insufficient?

Andy Stirling responded that, in his typology, adaptation is a strategy; system boundaries are rightly contested; and that standard economic approaches to diversity focus on known risks, rather than 'unknown unknowns'.

Further questions were: How do you choose what disparities to model? What policy drivers do you choose? How will you deal with opportunity costs, when there are many alternative transition paths? How should decisions be made to allocate scarce resources? What is the difference between flexible institutions and the current policy focus on 'flexible open dynamic economies'?

Tim Foxon noted that it is important to consider national and international policy drivers for both low carbon and energy security, and potential trade-offs between these. He noted that, as the future is uncertain, the transition pathways approach allows us to compare counterfactuals. As 80% reductions cannot be achieved by business as usual, the opportunity cost is not comparing with a business as usual case, but we are comparing alternative pathways for reaching this target. In terms of transitions, we can define the possibility space in ways that make sense, pathways with certain combinations of technologies. He takes the UK 80% carbon emissions reduction by 2050 as a normative target, based on science and accepted by policy-makers, and then the goal is to investigate ways of getting there. Flexibility of institutions may be needed to accommodate a transition, but how flexibility can be reconciled with the normative goal needs more thinking. Setting carbon budgets is an institutional innovation that will make explicit the gap between the incremental change currently promoted and the radical innovation that is required, and so expose the limitations of the current policy mix.

'The global deal: treating anthropogenic climate change as an economic internality'
Dr Terry Barker (4CMR, University of Cambridge)

Terry Barker gave a detailed talk, outlining his proposal for a global deal to address the twin *climate and financial crises* and reduce the systemic risks of wild weather and global depression. He argued that the G8 global 50% target or 450ppmv CO2-eq are probably not stringent enough to avoid dangerous climate change (IPCC, AR4), and so a zero-carbon global target is required by at least 2050. Current monetary and fiscal policies are rapidly worsening the credit crunch, by eroding trust in money. An urgent and strong global fiscal reflation, based on new investment justified by social values and discount rates, will take up resources left unemployed by the credit crunch, and kick-start the much delayed shift towards decarbonising the global economy. The costs of this will critically depend on international co-ordination, but could have an overall positive impact on GDP, due to the stimulus provided by this investment.

He argued that complexity or new economics is better than traditional economics at explaining the characteristics of the global economy: specializing production and generalizing consumption; competitive innovation and obsolescence; and long-term changes in patterns of industrial development and human behaviour. He argued that most equilibrium-based macro-economic models are unsuitable for analyses of the economy, the energy system or climate stabilisation, and that action to address climate change should be based on analysis of risks and returns of different options, rather than cost-benefit analysis, which is especially and unusually misleading (Weitzman). Anthropogenic climate change should be seen as a *whole-system internality*, i.e. a social behaviour that imposes costs on future generations, but which does not take into account these costs when decisions are made by present generations.

He proposed a seven-point plan to address the twin climate and financial crises:

1. Allow markets to work and bankrupt bad banks, whilst maintaining their institutional knowledge.
2. Co-ordinate a global interest-rate cut to zero.
3. Temporarily fix exchange rates (implement capital controls) and fix key international prices (e.g. carbon, coal, oil, gas).
4. Consolidate the bad debt into regional banks.
5. Reflate via an agreed global investment plan, supported by the good banks and scaled to maintain effective demand.
6. Reduce the risks of regulatory capture by a global regulatory authority having the power to "name and shame".
7. Reform international company law and standards to reduce costs of decarbonising the global economy.

Finally, he proposed a *new engineering* approach to decarbonisation. The problem separable into interacting engineered systems: electricity, vehicles, dwellings, offices, steel, cement, etc, that can be decarbonised separately, but a fit between them is required. Enabling structures and networks for a low-cost solution are key, including direct current grid; guaranteed global carbon and fossil-fuel prices; and technological agreements and standards. A Global Emission Trading Scheme (GETS) will be required for international transportation to decarbonise the sector and fund developing country mitigation and adaptation programmes.

Discussion
Prashant Vaze (independent researcher) began the discussion by raising the three large questions facing global climate policy-makers:

1. How to assess mitigation options, e.g. modelling efforts, what are BAU emissions going to be; marginal abatement curves, attempts to regionalise, opportunities to de-carbonise, below cost and above costs, etc?
2. Allocation question – there are worldwide abatement options, but who should fund what where?
3. These are static pictures, but need to make them much more dynamic. How do we ensure there are continuous incentives to innovate and deploy low-carbon technologies?

He then raised three implications for evolutionary/complexity economics:

1. How to turn global incentives into incentives for particular actors: e.g. Energy companies making investment decisions, in the absence of accurate foresight of future prices for carbon? Big infrastructure decisions, such as building new runway at Heathrow, what will be impact of carbon reductions on air travel capacity?
2. How to assess key role of rapidly industrialising countries, e.g. India/Brazil? How to balance climate, development and industrial issues?
3. What are dynamics of technology innovation? Low carbon technologies can be developed, but there is a path dependency to not deploying, which could become a self-fulfilling prophecy. Companies want to maximise return on investment, so there is a lack of incentive to scale up deployment.

Other points raised by the audience included the need to explicitly include uncertainty and normative assumptions in the analysis; does the analysis imply a continuation of the current model of global debt-based economic growth?; how could this new deal be operationalised?; what ethical principles should underlie global climate negotiations? what is the role of IP?

Terry Barker responded that his analysis is based on his experience from literature review and observation of what is happening, trends in the data. He argued that the world has seen a long period of non-inflationary growth, which has led to increasing prosperity for millions of people e.g. in China, which has been built on bad money, but could have been built on good money and de-carbonising the economy. He noted that the main policy prescriptions of the new economic approach remain investment and carbon pricing, but the application of these would be enhanced by Keynesian insights. He argued that the neo-classical approach to discounting welfare of future generations and unequal valuation of human life in different countries is unethical, and that zero personal discount rate and equal valuations should be applied.

Other contributors argued that we need a set of seven algorithms for analysis, based on the insights discussed over the last two days, rather than an inflexible seven-point plan; and we need an appropriate role for regulation.

Terry Barker responded that we need models to better reflect how people actually behave, and that neo-classical assumption of greed and self-interested behaviour could become self-fulfilling. He argued that we need a balance of fiscal incentives to encourage and regulation to force action, e.g. legislating for zero carbon cars by 2020.

Wrap-up session

'Opportunities and challenges'
Ronan Palmer (Chief Economist, Environment Agency)

Ronan Palmer concluded the seminar by offering his reflections on the two days. He would like a story that includes power (who does what?) and choice (what are the mechanisms for action?). We are not looking for a theory of just about everything, but a theory of something useful would be a good start.

His three main reflections were:

1. We need to address, in a more reflective way, the question of how politics and complexity economics are going to co-evolve, and need to examine systems of power, and systems of providing knowledge to power.
2. Remember, no matter how big you make the 'box' to include more things in your analysis, as we have bounded rationality, we are always going to be looking into a smaller 'box'.
3. Question of diversity and lock-in – when is a convention or other lock-in valuable, and when is it not?

Finally, he noted that there will always be things left outside the models, such as values and belief systems, that we still don't understand, but we need to reflect on.

Tim Foxon then closed the seminar by thanking all the speakers and participants for lively and insightful contributions and discussions.