Towards a New Complexity Economics for Sustainability:
Insights from a series of research seminars

Timothy J Foxon
Sustainability Research Institute, University of Leeds

Terry Barker
Cambridge Centre for Climate Change Mitigation Research, University of Cambridge

Jonathan Köhler
Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe, Germany

Jonathan Michie
Kellogg College, University of Oxford

Christine Oughton
Department of Financial and Management Studies, SOAS, University of London

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1. Introduction

This report summarises the outcomes of an ESRC seminar series on 'Complexity economics for sustainability'. Three seminars were held at the Universities of Oxford, Leeds and Cambridge between November 2008 and December 2009, together with a linked seminar at the University of Bozen-Bolzano in Italy in March 2009. This report was presented and discussed at the final seminar in the series, held at SOAS, University of London in September 2010.

The seminar series aimed to examine a range of new economic ideas being developed under the broad heading of 'Complexity Economics' and to investigate and test their relevance for informing policy-making on sustainability. Economic assessments are an important input to crucial policy making processes on climate change, food systems and other aspects of sustainable production and consumption systems. However, these do not always reflect the latest advances in economic thinking and so may provide limited or misleading policy advice. The seminars aim to synthesise exciting new approaches that are being developed incorporating ideas from complex systems theory, evolutionary and institutional economics, and economic and industrial history, but which have not yet had significant impact on environmental and sustainability policy-making.

This report introduces the research programme of complexity economics, its intellectual sources and insights, its key ideas, tools and techniques, and the initial implications for policies addressing environmental and sustainability challenges. The report summarises the lively and interesting presentations and discussions from the previous seminars, which are available on the project website at
http://www.see.leeds.ac.uk/research/sri/projects/esrc-research-seminar-series.htm

2. What is 'Complexity Economics'?

The term 'complexity economics' was coined by Brian Arthur[1] of the Santa Fe Institute. The core ideas were explained in the introductory lecture at the first seminar by Eric Beinhocker, author of 'The Origin of Wealth: Evolution, complexity, and the radical remaking of economics'.[2] In this approach, economies are identified as 'complex adaptive systems', differing 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.

Drawing on ideas of Richard Nelson[3] and others, Beinhocker argued that an ongoing process of co-evolution of physical technologies, social technologies (i.e. ways of co-ordinating human activities) and business plans underlies the creation of wealth in industrialised countries, notably as property-rights based market economies encourage

[1] W B Arthur (1999), 'Complexity and the Economy', *Science* 284, 107-109
[2] Beinhocker, E (2006), *The Origin of Wealth: Evolution, Complexity and the Radical Remaking of Economics*, Random House, London
[3] Nelson, R (2005), *Technology, Institutions and Economic Growth*, Harvard University Press

technological and social innovations for meeting consumer demands. He argued that this approach can inform how to enhance and spread more widely this prosperity, whilst recognising the limits imposed by human impacts on the planet's climate and ecosystems. However, 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.

Complexity economics draws together insights from a range of approaches that challenge conventional economic thinking. Each of these approaches is the subject of ongoing research and debate, and their application to environmental and sustainability issues is still in its early stages. However, each brings to bear insights that can enhance and enrich thinking and policy-making on these issues.

Complex systems thinking

Complex systems thinking highlights that individuals and firms, though lacking in perfect foresight, and able to learn and adapt over time, and typically interact through networks.[4] Emergent patterns arise out of these micro level behaviours and interactions, but these are only discernible at higher systems levels.

Evolutionary and institutional economics

Evolutionary economics assumes that individuals and firms have 'bounded rationality' and so follow habits and routines, which evolve by a process of variation, selection and retention.[5] Beinhocker argued that economic evolution is able to explain the explosive non-linear creation of wealth, increasing levels of variety and complexity, and spontaneous self-organization. Institutional economics highlights the role of institutions or 'social rule systems' in both enabling and constraining the choices of individual economic actors.[6] Economic evolution is thus argued to be strongly path-dependent, i.e. 'history matters', and technological and institutional systems may become 'locked-in', creating barriers to the adoption of more beneficial alternatives.

Ecological economics

Ecological economics highlights the dependence of human economic and industrial activity on the resources, waste assimilation capacities and ecosystem services provided by natural systems.[7]As Paul Ekins put it in his presentation, "The economy is a large and growing subsystem of the biosphere." This suggests the need to develop approaches and models that integrate ecological and economic factors, rather than merely trying to 'internalise environmental externalities', as neo-classical economic thinking aims to do. Koen Frenken and Albert Faber suggested that complexity economics represents a third generation of evolutionary economic modelling, which the evolution of natural systems is represented endogenously, as is technological and institutional evolution.[8]

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[4] Mitchell, M (2009), *Complexity: A Guided Tour*, Oxford University Press
[5] Nelson and Winter (1992), *An Evolutionary Theory of Economic Change*, Harvard University Press
[6] Vatn, A (2005), *Institutions and the Environment*, Edward Elgar, Cheltenham
[7] Common, M and Stagl, S (2005), *Ecological Economics*, Cambridge University Press
[8] Faber and Frenken, (2009), 'Models in evolutionary economics and environmental policy: Towards an evolutionary environmental economics', *Technological Forecasting and Social Change* 76, 462-470

Social and psychological understanding of human behaviour

As Lorraine Whitmarsh described in her presentation, recent social science research has generated a deeper understanding of the social and psychological drivers of human behaviour, particularly in relation to consumption of goods and services.[9] This implies that policies to reduce unnecessary consumption need to target multiple (not only economic) motivations, and to change social and institutional structures to facilitate this.

Social-technical transitions

Research has examined how systems transitions can occur through interactions between social and technological elements.[10] A key element of this is how existing dominant regimes are challenged, both by wider changes in the cultural 'landscape' and through activities in technological or market 'niches'.

Thus, complexity economics is able to draw on a wide range of theoretical resources, in order to address current environmental and sustainability challenges, such as

- What are the implications of these ideas for the mix of incentives needed to promote more sustainable patterns of behaviour by consumers and businesses?
- How to promote technological and social innovation for sustainability, overcoming inertia and lock-in of current technologies and institutions?
- Can a transition to more sustainable patterns of production and consumption be achieved in ways which are compatible with ensuring continuing spread of economic prosperity in both developed and developing countries?

3. Key tools, techniques and ideas

A number of tools, techniques and ideas were presented that are being developed to apply the insights generated by these theoretical approaches, including *systems analysis, input-output analysis, social network analysis, co-evolutionary approaches* and *new economic thinking*. Again, many of these are complementary and lessons can be transferred between them, but together they enable the application of complexity economics ideas to current environmental and sustainability challenges.

Systems analysis

Many of the presenters used some form of systems analysis to investigate the interactions between social, economic, technological and natural elements. Beinhocker described how economies can be understood as 'complex adaptive systems', consisting of many interacting agents. These systems transform energy inputs, typically in the form of fossil fuels and calories from agricultural production, into useful goods and services, which have high local order, at the expense of an overall increase in disorder or entropy, in the form of waste products, heat and greenhouse gases.

Andy Stirling argued that concepts of *sustainability* and *resilience* may be used to examine how dynamical systems can maintain and enhance the desirable properties of environmental integrity, social equity and human wellbeing under transient *shocks*

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[9] Nye, Whitmarsh and Foxon (2010), 'Socio-psychological perspectives on the active roles of domestic actors in transition to a lower carbon electricity economy', *Environment and Planning A* 42, 697-714.

[10] Grin, J, Rotmans, J and Schot, J (2010), *Transitions to Sustainable Development*, Routledge

and enduring *stresses*, both internal and external to the system.[11] Whilst *incumbent* institutions will favour strategies that seek to preserve the status quo, focussing on maintenance of incumbent technologies, traditional practices, monopoly firms and dominant industrial sectors, more *marginal* actors will often seek to pursue more radical strategies, involving engaging stakeholders, addressing multiple systems, exploring uncertainties, highlighting ambiguities and maintaining flexibility/diversity. He argued that a strategy of promoting *diversity* is generally effective in promoting stability, resilience, durability and robustness of systems. For example, he argued that a more sustainable set of energy technologies will have greater diversity, and that this analysis needs to incorporate disparities between different renewable energy technologies, as well as differences between renewables, nuclear power and coal, oil and gas as primary fuels.

Joe Ravetz argued for a dynamic and systems-based analysis of economic activity.[12] This would involve relating physical supply chains both to resource use and waste generation, and to the economic and social value cycles in which they are embedded. He argued for a relational approach, combining economic insights on investment and returns with social insights, such trust and reciprocity, and institutional contexts. Key themes of a relational economy approach include:

1. Economic flows, incentives and signals, focussing on the material exchange dimension;
2. Combining this with other dimensions – political, social and cultural;
3. To “re-socialise” the economy, we need links between these, both in theory and in practice, and at micro and macro scales;
4. Revisiting key assumptions and paradigms to break down barriers, such as a rigid boundary between production and consumption.

As an example of the policy implications of this approach, he looked at the competing discourses around the proposed (and failed) introduction of congestion charging in the city of Manchester. Here the claimed economic and environmental benefits of this scheme were defeated by arguments focussing on narrow views of economic costs and the strength of anti-government feelings. He argued that a ‘one planet transport’ discourse incorporating wider social and economic changes between all types of stakeholders could have been more effective.

Evan Fraser focussed on the challenge of adding some socio-economic perspectives to examining and anticipating global food security problems. His work with colleagues under the “Quantifying and Understanding the Earth System” (QUEST) program has aimed to find key socio-economic indicators that have made harvests in China susceptible to drought.[13] Examination of past drought events has found cases of both resilience, in which major droughts have only led to minor crop failures, and sensitivity, in which minor droughts have led to major crop failures. They then examined socio-economic factors that give rise to this increasing vulnerability. They aim to use this work to create ‘vulnerability maps’ which will identify regions that are

[11] Scoones et al. (2007), *Dynamical Systems and the Challenge of Sustainability*, STEPS Working Paper 1, STEPS Centre, University of Sussex

[12] Ravetz, J (2009), *Pathways Towards a One Planet Economy*, CURE, University of Manchester

[13] Simelton et al. (2009), ‘Typologies of crop-drought vulnerability: an empirical analysis of the socio-economic factors that influence the sensitivity and resilience to drought of three major food crops in China (1961-2001)’, *Environmental Science and Policy* 12, 438-452.

(1) likely to be exposed to drought and (2) unlikely to have the capacity to adapt. The generic lessons from this work are that scoping a problem down and taking a problem-oriented approach, is a useful way forward.

Input-output analysis

Klaus Hubacek presented an approach that combines ‘bottom-up’ life cycle anaylsis (LCA) of goods and services with ‘top-down’ input-output analysis at a country level.[14] In contrast to the current producer basis for calculating CO_2 emissions, this shows that the UK’s CO_2 emissions on a consumer basis have risen significantly since 1992, due to the embodied CO_2 emissions in imported goods from China and other countries. Despite efficiency improvements, China’s production-related CO_2 emissions have risen by 59% from 1992 to 2002, mostly due to large increases from construction and other capital investments, and from urban household demand. In the UK, the largest increases in the carbon footprint from final demand have come from travel and recreation activities. As well as scientific challenges of uncertainty and data collections, this raises policy and regulatory challenges. He argued for the need for a ‘shadow consumption-based indicator’ alongside official accounting, and for national actors to operate outside of their ‘territory’, for example by the UK investing in reducing production emissions in China.

John Barrett also highlighted the need to account for international trade in relation to carbon emissions. Economic growth, as measured by increases in GDP, has helped to alleviate poverty, but has not generally delivered improved welfare or happiness. In the example of the supply chain for meat products, a significant contributor to household emissions, there is relatively little scope for further efficiency improvements, and hence a need to focus on levels of consumption, in order to reduce emissions. Input-output-based tools can be used to calculate the environmental pressures associated with consumption activities.[15] In a study of the Leeds City-Region, the largest potential contributors to reducing the carbon emissions from the household sector were found to be retrofitting existing housing stock; behavioural change; and the adoption of low/zero carbon energy technologies. Emissions reductions of 38 $MtCO_2e$ were found to be possible by 2030, which would put the region on track for achieving the UK target of reducing emissions by 80% by 2050. However, no-one is currently implementing this required policy package at the regional level.

Social network analysis

Felix Reed-Tsochas gave an example of how a social network of firms in the New York City garment industry remained stable for a long period, despite high rates of firm entry and exit at the micro level, before eventually collapsing.[16] Jonathan Köhler examined the use of social network analysis to investigate how technological or market niches grow through networks of actors with common interests and complementary expertise coming together, leading to increasing returns to scale and non-linear growth.

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[14] Guan et al. (2008), ‘The drivers of Chinese CO_2 emissions from 1980 to 2030’, *Global Environmental Change* 18(4), 626-634

[15] Paul et al. (2010), ‘Introducing the Resources and Energy Analysis Programme (REAP)’, Working Paper, Stockholm Environmental Institute

[16] Saavedra et al. (2008), ‘Assymetric disassembly and robustness and declining network’, *Proceedings of the National Academy of Sciences (PNAS)* 105 (43), 16466-16471

Co-evolutionary approaches

Tim Foxon argued that understanding and analysing transition pathways to a low carbon economy 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; technological innovation systems, and evolutionary economics. This has been used to explain how the 'carbon lock-in' of current high carbon energy systems arises through co-evolution of technologies and institutions, driven by path-dependent increasing returns to adoption.[17] Here, two evolving populations co-evolve 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. 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.[18] 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.[19] This is examining pathways with different roles for government, market actors, and civil society, and different mixes of centralized and distributed electricity generation.

New economic thinking

Terry Barker 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 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.

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[17] G. Unruh (2000), 'Understanding carbon lock-in', *Energy Policy* 28, 817-830

[18] T.J. Foxon (2010), 'A co-evolutionary framework for analysing a transition to a sustainable low carbon economy', SRI Working Paper, University of Leeds

[19] Transition pathways to a low carbon economy, www.lowcarbonpathways.org.uk

4. Compatibility of economic growth and sustainability

The third seminar in the series focussed on the question of the compatibility of the continuing pursuit of economic growth in industrialised countries with social and environmental sustainability. A number of presenters contributed insights with a range of views on this crucial question. As described above, in his book and presentation, Eric Beinhocker argued that an ongoing process of co-evolution of physical technologies, social technologies (i.e. ways of co-ordinating human activities) and business plans underlies the creation of wealth in industrialised countries, but that this process is now under threat, as economic activity threatens environmental limits. He argued that 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.

Learning from historical energy transitions

Peter Pearson argued that energy systems are complex evolving entities and transitions involve interactions between *fuels and energy-converting technologies; infrastructures; institutions; policy regimes; economic variables; environment and resources;* and *people*. Britain's first Industrial Revolution from the 16th to 19th Centuries from a largely agricultural to a mainly industrial economy relied on using a fossil fuel stock (coal) for larger energy flows, which transformed growth and welfare. By 1650, half of the UK's final energy consumption came from coal, but the use of woodfuels took centuries to die out. Despite availability concerns, coal output and mining jobs did not peak until 1913. Economic historians such as Robert Allen have investigated the question of why the industrial revolution happened in Britain first. Allen has argued that the high wages and cheap energy and capital in Britain (compared to other countries) created a real return for labour-saving capital investments, such as steam engines, cotton mills and substitution of coal/coke for wood in metal manufacturing.[20] Work by Roger Fouquet and Peter Pearson has shown a negative correlation between energy prices and energy intensity (E/GDP) over five centuries. Successive technological substitutions have seen the cost of lighting fall to 1/3000 of its value in 1800 by 2000, leading to a 6500-fold increase in lighting use per capita, with high welfare benefits.[21] So, a long-run perspective suggests that new technology diffusion takes time, and that major productivity benefits of new technologies, such as steam engines or electric lights, were only observable decades after they were first introduced. Past transitions were not managed, and modern transitions could be faster, but it still takes time:

- to build new enthusiasm, infrastructure and institutions;
- to escape the shackles of path dependence;
- to overcome 'lock-in' and turn over old capital stock.

[20] R. Allen (2009), *The British Industrial Revolution in Global Perspective*, Cambridge University Press

[21] R. Fouquet and P.J.G. Pearson (2006): 'Seven Centuries of Energy Services: The Price and Use of Light in the United Kingdom (1300-2000)', *The Energy Journal*, 27(1)

Overall, Peter Pearson argued that the conclusion from the economic historical evidence is that major breakthroughs do affect aggregate productivity growth, but only slowly over a period of decades. It is important to recognize the complex interdependencies involved between technologies, institutions and users. The importance of relative prices between wages and resources in past transitions also has implications for the relative prices and availability of physical and human resources needed to drive risky low-carbon innovation.

Prosperity without growth

Tim Jackson outlined the arguments in his new book on *'Prosperity without Growth: Economics for a Finite Planet'*, focussing on the need for a new ecological macro-economics.[22] He began by setting out the 'dilemma of growth' – that economic growth is unsustainable, at least in its current form, but 'de-growth' (the shrinking of the economy) is unstable because, under present conditions, it would lead to rising unemployment, falling competitiveness and continuing recession. He argued that only a relative decoupling of environmental impact from economic growth has so far been made. To achieve the target of keeping global temperature rise to 2°C above pre-industrial levels would require a 130-fold improvement in carbon intensity to around 6 gCO_2/$ by 2050, for 9 billion people in the world to achieve an equitable income at around current European levels, assuming that industrialised economies continue to grow at 2% per annum, whilst other nations catch up. In the UK in recent years, growth has been driven by the pursuit of novelty for status consumption and increasing (labour) productivity, funded largely by personal debt, which has grown to over 100% of GDP, whilst the household savings ratio has dropped below zero. Tim Jackson argued that a different engine of growth is needed, in order to retain economic stability whilst remaining within ecological limits.

This new engine of growth would be based on ecological investment delivered by ecological enterprise. Ecological investment would target renewable energy and preservation of ecosystems and biodiversity, but would be likely to require lower rates of return over longer periods, and changes to the ways in which productivity and profitability of investments are measured, to move away from a focus on GDP growth. This would be likely to require restructuring of financial markets and a greater role for the public sector. Ecological enterprise would focus on supporting flourishing of people's lives, through low carbon, resource-light and/or non-material ways of people's needs. These 'Cinderella economy' activities would be primarily service-based, and focussed on providing jobs and supporting communities. These would not deliver high productivity growth, as conventionally measured, and so a structural shift would be required into more labour-intensive activities rather than high labour productivity areas, in order to maintain jobs. In turn, this challenges the idea of a consumer society, and implies the need to create an 'alternative' prosperity, based on social and psychological flourishing and the importance of participation. This would require building people's capabilities, and investment in public goods and shared public spaces, which is in conflict with the prevailing values of the current economic system. Tim Jackson's key message was that 'another world is possible', but that it would look quite different to the current world.

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[22] T. Jackson (2009), *Prosperity without Growth,* Earthscan, London.

Reconciling economic growth and environmental sustainability

Paul Ekins began his talk by setting out the accepted economic principles for sustainable economic growth, and arguing that these were systematically broken by the economic systems in industrialised countries, which led to the crash of 2008. He argued that we must start by getting right the basic conception of how the human economy relates to the natural environment, and that the language of 'externalities' is completely inadequate to understand the dependence of human economic activities on natural systems. It is important to distinguish between three types of growth:

- Physical growth: growth in the amount of matter/energy mobilised by the economy - *indefinite growth of this kind is impossible in a finite physical system*.
- Economic (GDP) growth: growth in money flows/incomes/value added /expenditure - *there is no theoretical limit on this kind of growth*.
- Growth in human welfare:
    - *dependent on sustaining environmental functions*;
    - *has a complex relationship to economic growth (though, ceteris paribus, more money is better than less)*;
    - *dependent on many other factors (employment, working conditions, leisure inequality/income distribution, relationships, security/safety of the future).*

Environmental sustainability depends on the maintenance of important environmental functions and the natural capital these functions depend on. An aspiration for sustainable economic growth must recognise the need for sustainable use of resources and ecosystems and be rooted in the laws of thermodynamics. To achieve stabilisation of atmospheric concentration of CO_2 at 450ppm, assuming ongoing economic and population growth (3.1% p.a. real), would need an improvement in carbon productivity (GDP/carbon emissions) by a factor of 10-15 by 2050, or approx. 6% p.a.. This 10-fold improvement in carbon productivity in 40 years contrasts with the 125 years the U.S. took to achieve the same improvement in labour productivity, and would be very hard to achieve within a system in which firms still have a strong incentive to improve labour productivity. The headline conclusion is that sustainable, green growth is technologically and economically feasible, but it would require sustained, wide-ranging and radical policy interventions to bring about technological revolution and change lifestyles. These interventions would be resisted by affected economic sectors (e.g. energy) and households who want to keep current lifestyles (e.g. transport), or attain Western lifestyles.

Moving beyond GDP

Jeroen van den Bergh argued that economics is very confused about the direction of causality between GDP growth and things that we value, such as happiness, reducing environmental pollution, creating employment and technological progress.[23] From a complexity perspective, it is not necessary to understand the full extent of economic complexity, just sufficient insight is needed to design policies and remove barriers. These barriers include (hidden) subsidies, the pre-occupation with growth, vested interests, lack of global government, and free riding (collective action problem). He argued that 'GDP' is the fundamental problem, not 'growth'. GDP growth is good in some periods/countries, but is not generally necessary or sufficient for progress. We need to understand better why there is persistent political support for the GDP

[23] J.C.J.M. van den Bergh (2010), Relax about GDP Growth: Implications for climate and crisis policies, *Journal of Cleaner Production* 18, 540-543.

indicator. The shortcomings of GDP as an indicator of social welfare or progress are well-known amongst economists, but its role in economics, public policy, politics and society remains influential – this is the '*GDP paradox*'.

Jeroen van den Bergh made it clear that being against GDP is not the same as being against growth, and that he took a neutral position on the need for growth. However, he argued that the goal of 'unconditional growth' is a constraint on the goal of improving human welfare, as it often frustrates good policy measures that would have direct benefits not measured by GDP. The growth aim is dominant politically, e.g. in the language of economic 'crisis', and ignores informal activities, such as unpaid child care. In particular, climate policy is frustrated by the goal of GDP growth, as economic cost-benefit analyses assume that less GDP growth is a cost. However, if GDP growth is 2 % per year, and the cost of climate policy ranges from US$1 to 20 trillion (6 % of total GDP over the period), then the delay time to reach a certain GDP level within about a century from now would be no more than 3 years. One solution is to use '*happiness*' as an indicator instead of GDP. It has been established that people's happiness or subjective well-being is delinked from GDP growth above a certain threshold income. This leads to the hypothesis that climate policy will be less costly in happiness terms than in GDP terms. Similarly, the main concern of economic 'crisis' policy should be reducing unemployment as this has tremendous happiness effects. So, an important challenge for economics is to discover how we can get full employment without the constraint of continuous growth. More work and employment may increase GDP, but this does not imply the reverse causality.

A Green New Deal: Climate change mitigation as an economic stimulus

Alex Bowen argued that there are a number of benefits to early climate-change mitigation action:

- induces innovation sooner (by enabling learning, scale and network effects);
- recognises that diffusion of new technologies takes time;
- encourages action by establishing a credible policy framework sooner;
- reduces the need for premature scrappage of capital;
- enables action to be strengthened if climate change proves more serious;
- provides greater benefits for win-win opportunities.

Recent modelling work suggests that the costs of stabilising at 450ppm would be up to 1.5% of GDP, provided that we do climate policy in a sensible way.[24] The proponents of a Green New Deal argue that the current global downturn makes tackling market and policy failures easier, as there are lower opportunity costs (temporarily unemployed workers), scope for temporary public spending increases, and potential for a boost to growth through fiscal stimulus. If policy measures are designed effectively, there may be higher benefit from spending on public goods under current conditions. Work by Alex Bowen and colleagues at the Grantham Institute argued for a fiscal stimulus of 4% of global GDP, of which 20% or around $400 billion a year should be focussed on a 'green' stimulus.[25] In fact, over $512 billion or around 16% of total stimulus packages across industrialised countries have been pledged, but this figure is over a number of years, rather than per year.

[24] B. Knopf et al. (2009), 'The economics of low stabilisation: implications for technological change and policy', http://www.pik-potsdam.de/members/knopf/publications/knopf_chapter11.pdf
[25] A. Bowen et al., 'An outline of the case for a green stimulus', Grantham Research Institute and CCCEP, http://www.cccep.ac.uk/pdf/AnOutlineOfTheCaseForAGreenStimulus.pdf

The economics of enough

David Fell argued that human societies are complex open systems, in which resources may be finite, but human ingenuity is not. They develop by a process of neo-Darwinian co-evolution, in which the structure of fitness landscapes determines the evolution and emergent properties arise at the macro level. Social networks influence the diffusion of change, and we are beginning to understand the mechanisms, drivers and critical paths. Institutions serve as commitment devices – they were fit for purpose at the point at which they evolved, but they can get locked in and influence other fitness landscapes, and so have power. Individuals have needs, ranging from basic needs to self-esteem, according to Maslow's hierarchy, and current institutions, designed to meet basic needs, may not be good at meeting higher needs. He argued that an 'economy of enough' should address four key co-evolved and inter-dependent areas:

(1) *The nature of work*:
This would move to tasks, instead of jobs, and create space for social entrepreneurs and a shorter working week, say 21 hours;

(2) *The accumulation of assets*:
This would focus on long-term security, through developing civic institutions and the return of trust;

(3) *Conspicuous consumption*:
This would aim to distance 'status' from 'consumption', by changing social norms and admitting fulfilment;

(4) *Energy addiction*:
To overcome our energy addiction would require greater decentralisation, and may require governments to take back some power from MNCs.

Steady state economics

Dan O'Neill argued for a steady-state economy, defined in physical terms as having a stable population; stable per capita consumption; energy and material flows that are minimised and within ecological limits; and constant stocks of natural and human-built capital. It is characterised by:

- *Sustainable scale*: energy and material flows within ecological limits;
- *Just distribution*: reducing inequalities;
- *Efficient allocation*: but only using markets where appropriate;
- *High quality of life*: measured in relation to health, time, prosperity and community.

In the last century, world population grew 4-fold and per capita GDP grew 6-fold, leading to a 24-fold increase in size of the global economy from $2tn to $47tn. This means that the economy has expanded rapidly in the relation to the environment, which provides resource inputs and assimilation of wastes, with environmental impacts strongly correlated with GDP. So far only relative, and not absolute, decoupling has been possible, e.g. from 1980 to 2005, GDP grew by 116% and material intensity reduced by 30%, meaning that total material use grew by 50%. Also, for incomes above around $9,000 per person, self-reported happiness no longer correlated with GDP increases. A model for the Canadian economy by ecological economist Peter Victor suggests that it is possible for an economy to have low levels of unemployment, poverty, debt-to-GDP ratio and GHG emissions, whilst GDP per capita stabilises.[26]

[26] P. Victor (2008), *Managing without Growth: Slower by design, not disaster*, Edward Elgar

5. Conclusions and policy implications

As the range of contributions show, 'complexity economics' represents an ongoing research programme, rather than a completed theory. However, some common threads are already emerging, which have strong implications for policy addressing current environmental and sustainability challenges, including climate change, impacts of current consumption levels on resource extraction and waste generation, and maintaining and spreading prosperity and happiness.

The key insights from complex systems thinking are that economies are open, *dynamic* systems, far from equilibrium, and are made up of diverse *agents*, who lack perfect foresight, but are able to learn and adapt over time. These agents interact through various social *networks*, and macro patterns *emerge* from these micro behaviours and interactions. *Evolutionary* processes create novelty and growing order and complexity over time. Other strands of social and ecological economic thinking emphasise that economic activity is embedded both in the ecological systems on which in depends and in the social systems within which it occurs. It has been argued that an ongoing process of co-evolution of physical technologies, social technologies (i.e. ways of co-ordinating human activities) and business plans underlies the creation of wealth in industrialised countries, but that a similar co-evolutionary process has contributed to the lock-in of current high carbon technological and institutional systems, inhibiting the adoption of low carbon alternatives. The dynamic, systemic nature of long-term industrial change highlights that learning, scale, adaptation and network effects can give rise to increasing returns or positive feedbacks in the adoption of new technologies and institutions, so that the more they are adopted, the more likely they are to be further adopted.

The general policy implications of this approach are that:

(1) Complexity economics provides a rich understanding of the behaviour of economic actors and systems, and that environmental and sustainability policy would benefit from taking into account this understanding.
(2) This is particularly relevant for policy aiming to contribute to a transition to a sustainable low carbon economy. Support for technological or market niches may be important to enable the innovation and deployment of low carbon alternatives.
(3) Tools such as systems analysis, input-output analysis, social network analysis and co-evolutionary approaches, together with new economic thinking, can be used to better understanding economic processes and systems.
(4) Policy needs to understand and address the drivers of consumption, as well as production. Social and psychological understanding of the behaviour of individuals and the influence of the social context on behaviour can inform the drivers of consumption, and how these can be influenced.
(5) New measures of the social and ecological value of economic activity need to be explored, to go beyond a reliance on aggregate indicators such as GDP.

A range of more detailed policy prescriptions were proposed by different presenters, but there was less agreement on the necessity or validity of these.

Eric Beinhocker argued that to achieve the necessary 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;
- Thinking should broaden beyond than current debates, e.g. female education in developing countries, green technology innovation clusters, catalysing infrastructure investments, and changing cultural norms.

Koen Frenken argued that 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.

Terry Barker proposed a new engineering approach to decarbonisation. The problem is 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.

John Barrett argued that changes to incentive systems were needed in relation to:

- *Fiscal policies*, to internalise externalities at the production stage, in order to 'use markets for what they are good for';
- *Infrastructure lock-in*, to reverse the commitment to road and airport building that encourages unsustainable transport patterns;
- *Awareness*, to encourage public debate;
- *Refine values*, to produce better measures of wealth and welfare, in order to indicate what is important to people.

Paul Ekins argued that environmental tax reform could stimulate low-carbon innovation with a small reduction in GDP, but would need to be complemented by other policies.[27] He argued that developing and deploying the technologies will require huge investments in low-carbon technologies right along the innovation chain (research, development, demonstration, diffusion), and that financing this investment will require a substantial shift from the UK's consumption-oriented economy of today to an investment economy that builds up low-carbon infrastructure and industries. Hence, it is not technology or cost that are the constraining factors to climate change mitigation, but politics – related to people's attachment to consumption rather than savings/investment, and aspects of high-carbon lifestyles.

Alex Bowen argued that the key elements of climate change policies are:

- A pervasive and steadily rising price for greenhouse gas emissions;
- The promotion of a shared understanding of what is responsible behaviour for firms and individuals in the face of the climate change threat;
- Tackling the market failures, including the under-provision of research and development, inadequate and asymmetric information about how to save

[27] Green Fiscal Commission (2009), *The Case for Green Fiscal Reform*.

energy and the difficulties in establishing new networks for energy supply, such as smart grids.
- Addressing policy distortions, such as fossil fuel subsidies, and to ensure the cost-effectiveness of policy implementation, in order to maintain economic and political support.

Dan O'Neill argued that to achieve a steady-state economy, countries would need to adopt the Steady State Economy as a macro-economic goal, and would gradually need to change existing policies from growth towards a steady state, including:

- *Limit resource use*: impose strict resource and emission limits, e.g. by imposing a cap-auction-trade system;
- *Stabilise population*: births plus immigration must equal deaths plus emigration;
- *Limit inequality*: must deal with distribution explicitly, e.g. by imposing a minimum and maximum income;
- *Reduce working hours*: shorten the working day, week and year, as technology progresses and efficiency improves, so that people receive the same salaries, but have more leisure time;
- *Reform the monetary system*: move away from fractional reserve banking, so that all money is created and spent into existence by the government, and banks have to borrow existing money in order to lend it;
- *Reform national accounts*: replace GDP with two sets of accounts: one measuring well-being, to be maximised, and one measuring resource use, to be minimised and kept within ecological limits.

Finally, Tim Jackson's policy proposals, draw together a wide range of social, ecological and economic research, but, of course, are far from universally agreed:

Establish the Limits
- Establishing clearly defined resource/emissions caps.
- Fiscal reform for sustainability.
- Promoting technology transfer and ecosystem protection.

Fix the Economics
- Developing the macro-economics of sustainability.
- Investing in public assets and infrastructures.
- Increasing financial and fiscal prudence.
- Improving macro-economic accounting.

Change the social logic
- Sharing the work and improving the work-life balance.
- Tackling systemic inequality.
- Measuring capabilities and flourishing.
- Strengthening human and social capital.
- Reversing the culture of consumerism.

Further research can help to demonstrate the likely effectiveness and efficiency of these policy proposals, but crucially experience needs to be gained from the practical application of these policies, for example, in particular market or local niches, to also inform their wider social and political acceptability.

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Seminar 1: 27-28 November 2008
Department for Continuing Education, University of Oxford

Speakers and discussants

Prof Jonathan Michie	Dept. of Continuing Education, University of Oxford
Dr Tim Foxon	Sustainability Research Institute, University of Leeds
Eric Beinhocker	Senior Fellow, McKinsey Global Institute
Professor Sir David King	Smith School, University of Oxford
Albert Faber	Netherlands Environmental Assessment Agency
Dr Koen Frenken	Economic Geography, Utrecht University, The Netherlands
Dr Felix Reed-Tsochas	CABDyN Complexity Centre, University of Oxford
Henry Leveson-Gower	GHK International
Prof Andy Stirling	SPRU, University of Sussex
Prof Christine Oughton	School of Economics and Management, Uni. of Bolzano
Dr Terry Barker	4CMR, University of Cambridge
Prashant Vaze	Independent Researcher
Ronan Palmer	Chief Economist, Environment Agency

Participants

Dr Jonathan Kohler	Sustainability & Infrastructure Systems, Fraunhofer ISI
Ronan Bolton	Sustainability Research Institute, University of Leeds
Kendra Wasiluk	Sustainability Research Institute, University of Leeds
Jean Boulton	Claremont Management Consultants Ltd
Miguel Castro Coelho	Prime Minister's Strategy Unit, Cabinet Office
Federica Cimato	Natural Environment Economics (NEE), DEFRA
Neil Witney	DEFRA
Pam Mason	Agriculture and the Environment Economics DEFRA
Dr Gill Coleman	School of Management, University of Bath
Prof Peter Reason	School of Management, University of Bath
Dr Matthew Cook	Economic Geography & Planning, Cranfield University
Dr Simon Dietz	Department of Geography and Environment, LSE
Emma Edworthy	Economic Adviser, Welsh Assembly Government
Neil McMurdo	HM Treasury
Anthony Moulds	Economic Adviser, Scottish Government
Michael Narberhaus	World Wildlife Fund
Mercedes Nattero	World Wildlife Fund
Dr Nazmiye Ozkan	Senior Research Fellow, Policy Studies Institute
Charlie Parker	Global Canopy Programme, Oxford University
Dr Joe Ravetz	Urban & Regional Ecology, Manchester University
Dr S Serban Scrieciu	4CMR, University of Cambridge
Dr Stanislav Shmelev	Environmental Change Institute, University of Oxford
Nicholas Howarth	Oxford University Centre for the Environment
Rachael Tily	rgt/research
Brian MacAuley	Economist, West Midlands Regional Observatory

Dr Neil Strachan	Senior Research Fellow, King's College London
Prof Peter Pearson	ICEPT, Imperial College London,
Dr Deanna Donovan	Joint Nature Conservation Committee (JNCC)
Eric Knight	Oxford University Centre for the Environment

Seminar 2: 23-24 June 2009
Weetwood Hall, University of Leeds

Speakers and discussants

Joe Ravetz	Urban and Regional Ecology, University of Manchester
David Feeney	Head of Planning & Economic Policy, Leeds City Council
Dr Klaus Hubacek	Sustainability Research Institute, University of Leeds
Dr John Barrett	Stockholm Environment Institute - York
Dr Lorraine Whitmarsh	School of Psychology, Cardiff University
Dr Jonathan Kohler	Sustainability & Infrastructure Systems, Fraunhofer ISI
Dr Evan Fraser	Sustainability Research Institute, University of Leeds

Participants

Jean Boulton	Claremont Management Consultants Ltd
Dr Tim Foxon	Sustainability Research Institute, University of Leeds
Prof Christine Oughton	Business School, University of Bolzano
Prof Jonathan Michie	Dept. of Continuing Education, University of Oxford
Tori Gretton	Independent Researcher
Mick Common	University of Strathclyde
Dr Paul Dewick	Institute of Innovation Research, University of Manchester
Harry Walton	Senior Economist, Environment Agency
Pat Devine	University of Manchester
Imogen Tennison	Sustainable Development Unit, National Health Service
Yingluk Kanchanaroek	Sustainability Research Institute, University of Leeds
Uzma Aslam	Sustainability Research Institute, University of Leeds
Paola Hernandez Montes de Oca	Sustainability Research Institute, University of Leeds
Marco Sakai Diaz	Sustainability Research Institute, University of Leeds
K Feng	Sustainability Research Institute, University of Leeds
Claire Bastin	Sustainability Research Institute, University of Leeds
Luuk Fleskens	Sustainability Research Institute, University of Leeds

Seminar 3: 3 - 4 December 2009
Madingley Hall, University of Cambridge

Speakers and discussants

Prof Tim Jackson	Sustainable Development Commission & Univ. of Surrey
Prof Paul Ekins	UCL Energy Institute, University College London
Dr Alex Bowen	Grantham Research Institute on Climate Change, LSE
Prof. Jeroen van den Bergh	Univ. Autonomous Barcelona, Spain
Prof. Peter Pearson	Centre for Energy Policy and Technology, Imperial College
David Fell	Brook Lyndhurst
Daniel O'Neill	Sustainability Research Institute, University of Leeds

Participants

Blake Alcott	Ecological Economist
Dr Terry Barker	4CMR, University of Cambridge
Katharine Bolt	RSPB
Jean Boulton	Claremont Management Consultants
Graham Boyd	Department for Business, Innovation and Skills
Cecilia De Ita	Sustainability Research Institute, University of Leeds

Dr Pat Devine	University of Manchester
Dr Peter Dickens	University of Cambridge
Dr Clare El Mouden	University of Oxford
Albert Faber	Netherlands Environmental Assessment Agency
David Feeney	Leeds City Council
Kuishuang Feng	Sustainability Research Institute, University of Leeds
Dr Tim Foxon	Sustainability Research Institute, University of Leeds
Clive George	University of Manchester
Stephen Green	Department for Energy and Climate Change (DECC)
Matthew Hannon	Sustainability Research Institute, University of Leeds
Paul Haynes	4CMR, University of Cambridge
Rosamund Healey	University of Cambridge
Paolo Hernandez	Sustainability Research Institute, University of Leeds
Nicholas Howarth	University of Oxford
Chao-Dong Huang	HM Revenue and Customs
Klaus Hubacek	Sustainability Research Institute, University of Leeds
Terence Ilott	Go East
Sudhir Junankar	Cambridge Econometrics
Scott Kelly	4CMR, University of Cambridge
Christian Kerschner	Univ. Autonomous Barcelona
Manuel Lecumberri F	London School of Economics
Henry Leveson-Gower	Department for Environment, Food and Rural Affairs
Dr George MacKerron	London School of Economics
Dr Chiara Mariotti	SOAS, University of London
Prof Christine Oughton	SOAS, University of London
Laura Owen	Sustainability Research Institute, University of Leeds
Hector Pollitt	Cambridge Econometrics
Albert Pompermaier	Department for Transport
Nicoletta Pratola	King's College London
Joe Ravetz	University of Manchester
Marco Sakai	Sustainability Research Institute, University of Leeds
Andy Skelton	4CMR, University of Cambridge
Robin Smith	The Systemic Fiscal Reform Group
Stephen Stretton	E3 Foundation
Philip Summerton	Cambridge Econometrics
Imogen Tennison	Eastern Region Public Health Observatory
Harry Walton	Environment Agency
Prof Adrian Winnett	University of Bath
Ozlem Yazlik	University of Edinburgh

Seminar 4: 6 September 2010
Brunei Gallery, School of Oriental and African Studies (SOAS), University of London

Speakers and discussants

Prof. Laixiang Sun	Dept. of Financial and Management Studies, SOAS
Prof. Christine Oughton	Dept. of Financial and Management Studies, SOAS
Dr Tim Foxon	SRI, University of Leeds
Prof. Paul Webley	Director and Principal of SOAS
Dr Adrian Gault	Chief Economist, Committee for Climate Change
Dr Nick Mabey	E3G
Prof Jonathan Michie	University of Oxford
Eric Beinhocker	McKinsey Global Institute
Tim Jenkins	Sustainable Development Commission
Ronan Palmer	Chief Economist, Environment Agency

Participants

David Bent	Head of Business Strategies, Forum for the Future
Marco Civitareale	CeDEP, SOAS, University of London
Ian Cooper	Eclipse Research Consultants
Sam Cunnington	Department for Environment, Food and Rural Affairs
Ruth Curran	Forum for the Future
Paul Dodds	University of Leeds
Dr Deanna Donovan	Joint Nature Conservation Committee
Prof Andrew Dorward	Head of CeDEP, SOAS, University of London
Dr Angela Druckman	Centre for Environmental Strategy, University of Surrey
Dr Craig Duckworth	London Metropolitan Business School
Albert Faber	Netherlands Environmental Assessment Agency
David Fell	Brook Lyndhurst
James Greyson	BlindSpot Global Revival Think-Tank
Prof Michael Grubb	University of Cambridge
Dr Paul Haynes	University of Cambridge
Mariane Jang	London School of Economics
Dr Yothin Jinjarak	SOAS, University of London
Tereza Kadlecova	Institute for Sustainability
Scott Kelly	4CMR, University of Cambridge
Elizabeth Krahulecz	Economic Attaché, Embassy of the Republic of Hungary
Prof Photis Lysandrou	London Metropolitan University
Ramona Meyricke	University of Cambridge
Dr Abay Mulatu	London Metropolitan Business School
Michael Mullan	Department for Environment, Food and Rural Affairs
Daniel O'Neill	University of Leeds
Alexandra Patel	Cambridge University
Alex Penn	ECS, University of Southampton
Hector Pollitt	Cambridge Econometrics
Alberto Pompermaier	Department for Transport
Dr Joe Ravetz	University of Manchester
Damian Ryan	The Climate Group
Andrew Skelton	University of Cambridge
Rosie Smith	Dept. of Communities and Local Government
Dr Jasmine Subaşat	Department of Development Studies, SOAS
Philip Summerton	Cambridge Econometrics
Prof Laixiang Sun	Head of DeFiMS, SOAS, University of London
Louise Sunderland	Association for the Conservation of Energy
Imogen Tennison	Quality Intelligence East
Chris Thoung	Cambridge Econometrics
David Vincent	The Carbon Trust
Dr Julian Wells	School of Economics, Kingston University
Mr Luke Wreford	One Planet Economy team, WWF-UK