Agent-based modeling, sustainable development and climate policy. A review of the Venice workshop April 2-4 2009

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1. Introduction

The event in Venice April 2-4 2009 was divided into two parts. The first part, titled *Agent-based modeling for sustainable development*, comprised the first two days and focused on agent-based modeling. The second part, titled *Financial Crisis and Climate Policy*, focused on the problems and opportunities stemming from the present confluence of two acute societal problems.

The event was part of a sequence of workshops and conferences on the general theme of new models for research in sustainable development. Recent events with similar themes were the Dahlem Conference on *Mathematics and Social Sciences* held at Frei Universität Berlin December 14-19 2008, and the workshop titled *Towards the neXt generation of climate policy models* held in Berlin November 13-14 2008. A later event on the topic "Modelling for Sustainability" was held May 11-12 in Beijing, China. Please refer to *http://www.european-climate-forum.net/* for further information on past and upcoming events.

The Venice workshop was arranged under the EU FP7 Coordination Action *Global Systems Dynamics and Policies* by and in collaboration between the European Climate Forum (Carlo Jaeger and Aida Abdulah – Berlin, Germany), Chalmers University of Technology (Kristian Lindgren and Claes Andersson – Göteborg, Sweden), the European Center for Living Technology (Elena Lynch – Venice, Italy) and the Foundation Eni Enrico Mattei (Venice, Italy).

2. The first day, April 2

Allowing for the learning-by-doing[1] that is necessary when holding a workshop in the middle of the beautiful Venetian labyrinth, the first day

[1] With doing here meaning getting lost.

started at 10:30 in the morning with the following days starting half an hour earlier each. The first day started with an introduction by Kristian Lindgren. He stated that the long-term ambition of agent-based modeling for sustainable development is "to produce a new generation of models allowing the identification and evaluation of major policy options for sustainable development that remain hidden to the class of models currently in use." He also stated the three general themes around which discussions would be held:

1. Empirical, theoretical and computational aspects of modeling agent behavior
2. Strengths and weaknesses of the supply and demand framework: examples, challenges and alternatives
3. Practical relevance of price vs non-price policies for sustainability

2.1. Session 1: Empirical, theoretical and computational aspects of modeling agent behavior

After the introduction, John Finnigan (director of the CSIRO Centre for Complex Systems Science) started off the session on the theme "Empirical, theoretical and computational aspects of modeling agent behavior" by providing an overview over agent-based modeling (ABM) that was very well received. This was fortunate not only because it provided a number of highly concrete demonstrations of ABM models in use but also because it got the debate that followed started. The discussion touched upon a number of topics:

1. **Simple versus complex models** ABM models clearly allow, and even invite, details. That is, one of its potentials is the inclusion of many features of the modeled system. Doing this could lead to increased realism, but it also leads to the suspicion that the model might not be trustworthy. This is so not least since complex systems are notorious for amplifying errors rather than canceling them out; i.e. they are often highly contingent. A way around this problem is to use simple models that pick out the most salient features of the modeled system by abstraction. Such models are simpler and easier to argue for and against. They are, however, not necessarily useful for the same purposes; more on this shortly.
2. **Defining and characterizing ABM** The basic question "what is ABM?" is important but very hard to answer in a conclusive way. Some think that definitions are highly important while others are

not of that opinion, thinking that local definitions are important while universal definitions rarely lead to conclusions and are in any event rare and not necessary for progress. Perhaps the major benefit of this general question is that it can fuel discussions on its topic, even if it is unlikely to yield some timeless and all-inclusive resolution. Takes on the subject included emphasizing the autonomy of agents, i.e. that agent can have perspectives on the system that are local to themselves and that they can act without central coordination; something that of course happens in many real systems and that is otherwise hard to model. This can be contrasted with the representative agent approach that is more common in mainstream economics. Nicola Botta here proposed a negative strategy: characterizing what is *not* ABM and why it is not.

3. **The need for a common language** Carlo Jaeger brought up the issue of a common language. If ABM is to be successful, then models can not be monadic. One could say that progressive science is characterized by its ability to build new results on previous results. For this to be possible, there has to be a degree of commensurability between models. Individual models and their agents, however, do not only reflect the "content" of the model, if we by this means what the model says about the modeled systems. They also contain a lot of features that are contingent upon their particular implementations. The fact that these implementations tend to differ greatly, mixing the contents of models becomes very hard to do. One way to deal with this problem is to minimize the implementation-specific variation between models. This, however, carries with it a cost of decreased flexibility and might mean less computationally efficient and/or less elegant models. Another way is to have a way of clearly expressing the scientifically relevant content of the models, such that it becomes clear what specific implementations (however they are realized) should achieve.

4. **That ABM has a number of quite different uses** ABM, just like mathematics or any other modeling technique, is not used for one single type of problems. This needs to be acknowledged as it, for example, affects the problem of devising common languages or simulation platforms. It is for example not certain that models used for specific data-driven scenarios (e.g. simulations of particular regions or systems) have the same set of needs and considerations as abstract models dealing with types of systems and more concerned with explaining than with providing scenarios. Measuring one according to the standards of the other might not do it justice.

It might be that a common language or platform for ABM is to bite off more than one can chew, and that sets of such devises, each adapted to their own small areas (say traffic, geograophical models, energy systems, etc.) but at the same time similar enough to be somewhat mutually understandable, might be a better option.

5. **Validation** What does it mean to validate an ABM? Validation is indeed a troublesome term to begin with as it is a legacy of old absolute theories of truth where the issue of whether something was ideally true or not was of sublime importance. Although validation is today used in the more tempered sense of strengthening or weakening the thesis that a model is sound, the question still lurks: what happens when a model is validated? Is it then true and if so in what sense? Models need to be tested somehow against real-world data, so much is clear. However, they were different views on what validation should consist of. Reasonably, strategies for arguing for and demonstrating the merits of a model must depend on what the model is used for. For example, a model of pedestrian traffic and a Sugarscape-like model might both model the mobility of humans. However, in the former case, the exact details of the model component for mobility might be much more critical to the performance of the model than in the latter case.

6. **Accounts by different researchers on why they use ABM** A number of senior researchers were asked why they work with ABM, and what stood out (in the opinion of the author of this report) was that the interest in abstract/simple models seems greater than the interest in models of particular systems. Perhaps there are many fundamental things about societies that must be understood before the approach can be trusted enough to be put into wide use for very detailed studies. That is (which ties in to the need for, and current lack of, a common language or set of languages), that we do not have enough well-tested knowledge and method to lean on unless the models are so simple that we can pull off a full stand-alone explanation and defense of a model within (more or less) one single publication. The reason that things can be communicated with such brevity and conciseness in for example physics is not that there is no need for strict and careful explanations of the models, it is that such explanations are already made, well established and need not be repeated for every new study.

2.2. Session 2: Strengths and weaknesses of the supply and demand framework: examples, challenges and alternatives

The second session started with a presentation by Dr. Antoine Mandel of the Potsdam-Institut für Klimafolgenforschung (PIK). Antoine began by explaining how supply and demand is rendered in neoclassical economics and then proceeded to introduce the Lagom[2] model developed at PIK (MFL+09), where supply and demand is simulated explicitly rather than subsumed. The presentation did not only introduce the Lagom model family, but also, by opposing and relating traditional models (Walrasian auctioneers, representation agents, etc.) to an ABM approach, it also highlighted and provided examples of more general problems.

The presentation was followed by a debate where many topics were discussed. For example, i) what is the difference between systems dynamics models and ABM? Systems dynamics models and ABM share the feature that they are dynamical. What are the differences between them? ii) How do models map to particular systems, such as to time series and local areas? Even if the dynamics of the model can be mapped to real time and space, many other types of dynamics are often used that do not have direct real counterparts. For example, say that an evolutionary adaptation is used to model pricing, then there will be a dynamics that does not map directly to anything that happens in the real world. iii) Can one model catch the whole world? This question is interesting for many reasons. Even if there is likely to be fundamental mechanisms that are common to all human societies, is there anything to gain by placing models on such a low level of description that all qualitative differences between different parts of the world emerges from the bottom-and-up? Is this even possible? Should one instead, if one wishes to indeed model the whole world, devise a set of different models that are linked? iv) Carlo Jaeger stressed the importance of getting supply and demand right in models, and he argued for how equilibrium models fail to do this in some important respects. v) Many

[2] For those interested, let me provide a short etymology of the word “lagom” in Swedish. “Lag” means “team” or “party” in Swedish, but it also means “law”. The most common etymology (and one I have perpetuated myself) is that it has to do with the former sense of “lag”, in conjunction with “om” (“around” in English, simply “um” in German) so that it would mean “around the party”. This, evidently, is wrong. “Lagom” was instead originally a dative plural of “lag” in the sense of “law”, but referring generally to a common understanding or agreement. So if something was done “lagom” it would be done in agreement with understanding, law or what was just. Swedish does not use dative forms anymore (except in certain dialects) so this is far from obvious to modern Swedish speakers.

of the questions that came up and that interested many researchers were of a conceptual and fundamental nature. What types of models are needed to address these questions? Do we need complicated models or are simple models better? As mentioned before, ABM models can be made arbitrarily complicated, and in some applications this is a strength, but for many purposes, parsimony may be more important than details.

3. The second day, April 3

3.1. Session 3: Practical relevance of price vs non-price policies for sustainability

The session began with an introduction by Carlo Jaeger to bring up a number of issues and to seed the following debate. Carlo questioned for example the value of calculating the cost of large future events and compared this practice to the type of exercises that some medieval Scholastics engaged in, such as calculating the number of angels that can dance on the head of a pin[3]. What was the monetary cost of World War I? How many euros is Venice worth? These questions do not necessarily make much sense and neither do they seem necessary in order to understand the horrors of wars and the value of preserving historical heritage. In other words, there is a tendency for producing figures also when the basis of these figures is highly dubious. While a short-term effect of raising the awareness of certain issues may be helped (if the option to a fictitious cost-benefit analysis is ignoring the problem) by coming up with a quantified monetary value, the long-term effect may be highly deleterious: the absurdness of calculating the monetary value of something irreplaceable can undermine confidence in the scientific community and it perpetuates the conception that whatever lacks monetary value universally lacks value. Carlo furthermore noted that insurance agencies, who are faced with real consequences of producing meaningless figures, indeed have developed methods other than cost-benefit analysis for assessing situations where monetary values cannot be properly calculated.

Carlo also noted how the current financial crisis has brought problems with current models of the society even more into the light. As a

[3] There are a number of versions of this example of what the Scholastics engaged in. It seems that it probably does not have a firm historical foundation but is more of an invented caricature used for discrediting Scholasticism in the days when it was still influential. Nevertheless, literally accurate or not, its survival and popularity indicates that it still illustrates a human tendency.

parallel, he noted (a parallel that unfortunately gained actuality only a few days later further to the south in Italy) how we generally accept that science cannot predict exactly when and where earthquakes will happen. Hence the occurrence of an unpredicted earthquake is not seen as scientifically troublesome. However, if science would preclude the possibility of earthquakes, or rest on the assumption that earthquakes do not happen, that would on the other hand be seen as highly problematic.

One thing that was discussed in the following debate was the nature of non-price controls. Many laws are in general examples of non-price controls and Carlo took as an example a Swiss constitutional regulation that the amount of forest in the country should be constant. That is, it does not matter what you pay to go below or above the prescribed amount of forest: doing so is not just illegal, it is against Swiss constitution. Price control and fines can have the same effect but can have less wanted by-effects that in some circumstances may be highly undesirable, such as in effect acting as laws for some but not for others. It may also be problematic to find and maintain the right price to attain the desired effect. Another aspect of price control is the question of who gets the money?

In general, there was much discussion about various factors that importantly affect societal dynamics but that are typically left out of current models. Examples include more subtle features of the energy systems, such as the consequences of supplying large parts of Europe's energy demand from German wind power. What happens when there happens to be no wind? In other words, one type of electricity might not be substitutable to other types of electricity. The effect of cartels on prices is another example. There is often a small number of large actors, which gives us only a handful of very complicated agents that may not even engage in competition. This is highly problematic from a modeling perspective, but no less important because of that.

The question of "optimal challenge" was also brought up. According to Jane Jacobs(Jac69), for example, an optimal city is a dead city. It is in the face of challenges that progress is made, so minimizing trade friction, leading to more and more regional specialization, might counter-intuitively give the well greased system a long-term disadvantage compared to less optimized economies. West Germany and Great Britain in the post war decades were taken as examples of this. By all indications, Great Britain was much more attractive for industrial growth than West Germany, yet in the end, the need in West Germany to counter disadvantages resulted in innovation and the outcome was rather the reversed.

Furthermore, John Holmberg related the discrepancy between how large a portion of higher consumption that goes into increased energy use, while at the same time the things that people say increase their happiness are not energy intensive. This raises the question about in what sense humans work to increase their utility: is it long-term or short-term utility, in what ways do these differ. This is hardly anything that is incorporated in present models.

The need for sensible agent analysis was also discussed. Klaus Hasselman and Julian Hunt related a couple of anecdotes (at different times during the workshop) that recounted the specific chain of events surrounding rather important policy decisions. In revealing how personal, cultural and contingencies affect even very important and large societal events, such anecdotes have an amusing effect since they contrast greatly to how one would perhaps expect and wish that important policy decisions are made. These contingencies make some sort of sense in hindsight but they are completely impossible to guess *a priori*, unless possibly for persons with a very intimate knowledge of the particular set of people, cultures and circumstances that are involved. In other words, they are the exact opposite to general rules and are a modelers nightmare.

4. The third day, April 4 – The ECF Annual Conference

The three-day-event was divided into a workshop on agent-based modeling during the two first days and the annual conference of the European Climate Forum on the third day. In practice, the audience was highly overlapping, they were held in the same room and were on highly compatible topics, so from the perspective of an attendant, they may well be seen as contiguous.

The invited speakers on the ECF conference (and the titles of their seminars) were:

- **Welcome** Prof. Klaus Hasselman, Max Planck Institute of Meteorology, Hamburg, Germany

- **A Global Challenge** Prof. Antonio Navarra, Euro-Mediteranean Centre for Climate Change (CMCC), Bologna, Italy

- **Implications of the financial crisis for climate policy** Prof. Carlo Carraro, Research Director of FEEM, University of Venice, CMCC, Venice, Italy

- **What Lessons from Climate Policy for the Financial Crisis?** Prof. Peter Hoeppe, Head of Munich Re's Geo Risks Research/Corporate Climate Centre, Munich, Germany

- **The 'Diabolical Problem' - Climate Policy, Global Change and the Global Financial Crisis** Prof. John Finnigan, Director of the CSIRO Centre for Complex Systems Science, Canberra, Australia

Please also refer to the presentations of the *Financial Crisis and Climate Policy* event, which are available at *http://ecf.pik-potsdam.de/ecf-annual-conference-2009.*

4.1. "Welcome and introduction to the conference" by Prof. Klaus Hasselman

Klaus Hasselman began by framing the conference (and to a large part the whole event) in terms of an opposition of two possible tendencies of societal system and their associated methodological approaches and techniques: "General Equilibrium" and "Inherent Instability".

The general equilibrium view of society has very strong methodological benefits and the theoretical basis is strongly developed; so much so that it is a powerful shaping force in how society is viewed. Klaus mentioned that the methods are based on mathematical analysis and listed as defining key words *convexity*, *fixed point theorems* and *optimization.*

The inherent instability view is methodologically challenging in a different way than the general equilibrium view just mentioned. In a sense, this view involves taking seriously all those features that can *not* be studied analytically. The problem with taking these features seriously is that we find ourselves with a serious shortage of theory and largely without the powerful aid of mathematics. This used to be a handicap that was so crippling that many used to think that it was not worthwhile pursuing at all: it could not be done in a strict manner. Now, computers give us the ability to simulate these systems and this presents us with an opportunity; an opportunity that is underscored by the heightened sense of urgency that has followed with financial upheaval and the threat of impending and serious problems with unsustainable development. Klaus here characterized the methods used with the terms *system dynamics* and *agent-based modeling*, and exemplifying software tools commonly used by *VENSIM* and *SWARM.*

The real world was illustrated by means of clouds, indicating a sense of uncertainty, detail or irregularity. Finally a menacing red cloud with the text “2008-2050” scared the mind out of a face under the “General Equilibrium” column and caused another face under the “Inherent Instability” column to display a content and perhaps even a little secretive smile. Beside the mildly smiling face was the text “Opportunity”, indicating that with computers to our aid we can at least get a chance to grapple with the problem of the long term (over which the society is most clearly not in equilibrium) in a fair fight.

4.2. “A Global Challenge” by Prof. Antonio Navarra

Antonio began by giving the audience an overview over climatic time series clearly showing that temperatures have an increasing trend and that there are consequences of this trend. For example, the extent of Arctic sea ice, the melting pattern of polar ice sheets and the temperature of permafrost in Alaska. He then posed the question of how it is possible to pose climate as a scientific question. After all, there are no crucial experiments, such as the Michelson-Morley experiment in physics[4]

The strategy of climate modeling, clearly, is very different from that of the study of societal systems. The problem in modeling climate is much more directly due to the intractability of models that are known to represent the system quite well. Errors and uncertainties are there, but they are typically not of the type that Lane and Maxfield (LM05) referred to as “ontological uncertainty” but of a mathematical, computational and statistical character[5]. Antonio compared coming generations of climate models to increasingly powerful microscopes that give us the ability to compute the future climate with increasing resolution and confidence. The evolution of this resolution was illustrated with maps from outputs of models of different generations.

Such models are of course not just, or even mainly, useful as crystal balls but are used for exploring what-if scenarios. That is, they are used for exploring the consequences of changing the value of parameters

[4] Author’s note: It turns out, on closer scrutiny, that the impact of the Michelson-Morley experiment did not exactly follow the idealized textbook description(Lak78). Indeed, the falsificationist ideal picture where theories are disproved by crucial experiments was much elaborated also by Popper himself(Pop79). Falsification is crucially important for science but there is simply no evidence of silver bullets against major theories. Indeed, Newtonian mechanics, relativity theory and quantum theory all waded in falsification for decades before coming into their right. However, the point that the potential for well-designed experiments with a strong falsifying/corroborating potential is stronger in some areas of science than in others, and that such areas are more progressive, can be defended.

[5] Ontological uncertainty has to do with uncertainty that lies in the model formulation itself rather than in its parameters or states. It is an endemic type of uncertainty in models of societal systems.

whose real counterparts we (at least potentially) have some control over; e.g. pollution levels, technology and so on. The outcomes, be they good or bad, are then important for motivating risks and costs of making the corresponding adjustments.

Antonio further characterized the challenge of climate change by stating that it is a strongly science-based problem, that it is a special responsibility for scientists to provide sound, honest and accurate reports and that the problems have a global scope and are characterized by complex interactions. Climate change is one of the modern societal problems that are of a complexity that demands scientific attention: science may not have all the answers right away, or even ever. For all its imperfections, science is still, however, the only institution with a track record in the systematical development of this sort of knowledge.

The obligation to provide unbiased, sound and accurate reports is clearly of utmost importance: the only true mandate that science can have in policy comes from whether or not it leads to sound decisions that work. Sound work builds the credibility capital that science needs to have an influence, unsound and opportunistic work squanders this capital over the long run. But this obligation extends also to policy-makers and funding agencies, they must be careful with what they favor and what they do not favor: they must make academic honesty possible. They must, as Antonio said, ensure the autonomy of science. For example, they must not fall for the temptation to appropriate parts of science's credibility capital for political purposes.

Four elements for a post-Kyoto regime were presented:

Effective Capable of realizing significant emission reduction

Empowering Allowing emerging countries to continue their development path

Fair Recognizing the historical responsibility of mature economies

Shared A large societal consensus is needed to implement the policies effectively

This must be done against a background that Antonio characterized as exhibiting a "happiness gap": people seem reasonably content with their personal lives but not with the state of society and in particular not with the direction in which it is headed. People perceive growing threats that they think their governments are ill equipped to handle effectively. So the problem, then, is to find policies that tackle these problems while at the same time minimizing the impact on the private satisfaction of the individual.

4.3. "Implications of the financial crisis for climate policy" by Prof. Carlo Carraro

Prof. Carlo Carraro spoke about the issue of how the recent global financial crisis may come to influence climate policy. Carlo began by setting up two main groups of implications: finance and governance. Are the costs of climate policy too high? Are there new different priorities induced by the economic crisis? As for governance, does climate policy require global cooperation? Can the economic crisis favor a global deal on climate policy?

Carlo noted that most financial projections come up with relatively low figures (in percent of GDP) for the cost of reaching quite ambitious greenhouse gas emission targets. But what are the assumptions that go into these projections? Different models embody different sets of assumptions but they all tend to be optimistic about the deployment of carbon free technology and about the outlook for global cooperation on these issues. If these assumptions are dropped then the projected cost rises quite significantly. Carlo then displayed a number of plots juxtaposing the projections of different models, including IMACLIM, REMIND and WITCH.

What are the factors that affect the outcome of cost-benefit analysis models, and in particular what are the factors that lead to gloomier predictions? Carlo displayed a plot where a number of events and their impact over the coming century: a technological impasse, delayed global action and fragmented participation. These were compared to the standard case. The result was that the difference in 2030 was very small but as time went on the increased cost of these complicating factors increased dramatically, with a technological impasse preventing new technology from being deployed projecting costs of almost 15% of GDP by 2100.

Summing up the first part, Carlo concluded that cost benefit analysis indicates that the standard 1%-of-GDP cost estimate is not supported. With a target of 550ppm of atmospheric carbon dioxide, 3% of GDP is a more likely projection, and even higher if action is delayed. Costs are also likely to be higher in the developing world. Finally, the economic crisis could rearrange the priorities so that resources are spent on other development instead.

But what would the costs of climate policies be over the short run? Are they so large that they are incompatible with for example the recent bailout packages and investment plans brought about by the crisis? Carlo argued that the financial requirements to stimulate energy research and development, the development of carbon capture and storage plants and policies for increasing the penetration of solar and wind energy are not excessive and in any case substantially lower than the sums already committed to protect the financial system. So, Carlo summed up, why not protect our future lives?

Concrete lessons about governance include that ambitious targets cannot be achieved without the participation of all countries, with the possible exception of Africa. China and India are of course indispensable, but so are other regions. Their participation, furthermore, can only be slightly delayed. The modeled performance of various coalitions were also compared.

The issue of stability, furthermore is important. No coalition is stable due to short-term gains by defecting on a collaboration. Therefore, there must likely be a system of incentives, transfers and policy linkages. Could some policy device/institution emerge from the needs imposed by the financial crisis that could be helpful also for making cooperation over the climate possible? This seems unlikely and it is more likely that the global crisis may hurt climate cooperation by delaying action.

4.4. "What Lessons from Climate Policy for the Financial Crisis?" by Prof. Peter Hoeppe

Prof. Peter Hoeppe began by noting that parts of the financial industry has indeed had its eyes open to long-term hazards such as global warming for a long time. Perhaps it is not surprising that the part in question is the insurance industry whose long-term success depends on managing risks; be they easily quantifiable or not. Peter, who works at the Geo Risks Research and Corporate Climate Centre of Münchener Rück (MR)[6], evidenced this by an excerpt from a publication of MR on flood and inundation from 1973 where it was not only noted the mechanism behind global warming and its potential hazards in the future but also the fact that this issue had hardly been researched at all.

In fact, in a survey over seventy insurance industry analysts around the world where the goal was to name the top five risks facing the insurance industry, climate change was ranked as number one. Some statistics over the yearly number of natural catastrophes and the extent of their effects explained some of the background of this sentiment: the curves do seem to show a robust increase in climate-related disasters natural disasters over the past three decades while the trend in geophysical events is very small and, one must assume, random over such minuscule timescales.

[6] Munich Re (in English) is the world's largest reinsurance company, based in Munich, Germany.

Peter explained how MR together with a range of other institutions[7] has initiated the Munich Climate Insurance Initiative (MCII). The aim of this initiative is: "Development of risk transfer solutions to support adaptation mechanisms to global warming in developing countries in the framework of the UNFCCC[8]-process". By doing this, the practice and theory of risk management developed under live conditions, so to speak, by the insurance industry can be applied to the problem of mitigating future damages. The role envisioned for the insurance industry was summarized in four points:

- Provision of data on weather-related losses to science, political decision makers and the public.
- Transparency of risks via risk measurement and risk adequate premiums → sound actions, prevention and reduced loss loads for society.
- Products promoting society's emission reduction goals.
- Products enhancing society's hazard-adaptive capability.

Furthermore, Peter provided specific examples of the role of insurers in tackling some inherent risks associated with renewable energy sources. For example:

- Neither solar nor wind energy are constantly available; they vary naturally.
- The most favorable locations for solar energy are located far away from the areas where the demand for electricity is highest (typically the Sahara desert → Europe). Long distance electricity transit carries with it uncertainties.
- For geothermal power there are risks involved since there is no guarantee for finding water with sufficient volume and temperature for profitable generation.
- Much of biomass production is exposed to the same hazards as agriculture when it comes to poor harvests.

[7] The other partners are: Germanwatch, IIASA, Potsdam Institute for Climate Impact Research, Tyndall Centre, the World Bank and a range of independent experts.
[8] The United Nations Framework Convention on Climate Change, produced at the UN Conference on Environment and Development (UNCED) in Rio de Janeiro 1992.

– Emissions trading carries with it risks as well. For example, cover could include that the investor is compensated for losses if the carbon credits are not delivered according to plan while the investor itself needs to deliver to a secondary market buyer to comply with reduction requirements.

4.5. "The 'Diabolical Problem' - Climate Policy, Global Change and the Global Financial Crisis" by Dr. John Finnigan

A central aspect of what Dr. Finnigan called "The Diabolical Problem" is that the world is more and more becoming one great interconnected dynamical system and that such systems are much more prone to failure than what is generally known and acknowledged. John provided a number of examples of problems that are facing us in the future; what they are, their causes and how they are interlinked.

The four main drivers of global problems were identified to be: i) population, ii) aspiration, iii) connectivity and iv) biogeochemical change. *Population* denotes the problem of population growth with the background of food and water supply problems, sanitation, diseases and social problems. *Aspiration* denotes the drive for development and in particular for sustained GDP growth. *Connectivity* is the range of problems stemming from an increasing interconnectedness of human activities across the globe. This is perhaps the most non-standard of the four drivers since its status as a problem becomes evident only when taking some quite recent advances in complex systems research into account. Indeed, increasing interconnectedness is not seldom seen as something entirely positive whose negative externalities are vastly outweighed by its positive effects. Finally, *biogeochemical* change is the by far the most illustrious of the four since it includes global warming and the greenhouse effect as its most prominent members.

John noted that all these four drivers have substantial inertia over the time scale of a few decades and some may involve processes that are highly fundamental to how the systems works and that by that are also hard to affect without very far-reaching measures. Furthermore, there are many factors of change whose nature and existence are poorly understood or conjectural. An example of this is the demographic transition between large and small family sizes that is statistically well established as happening as GDP per capita increases. What in fact causes this transition is less clear and controversial. Another factor is the impact on growth aspiration by the interconnectedness of the world. Not only does interconnectedness seem to promote growth, knowledge of what is possible elsewhere is also likely to increase the aspirations of less affluent parts of the world. The growth of GDP itself, whether it causes the interconnectedness, is caused by it, or whether there is no diachronic causal relationship but rather that both are entailed by a common process, is in any case a force that seems to have a life on its own. John here lists estimated global per capita GDP values for three historical points in time: 1000AD ($480), 1820 ($710) and 1998 ($5700). The global economic system is also known to have the character of being scale-free, which suggests that it grows preferentially. Driven by a process that by all likelihood is highly basic (see e.g. (AHL05)), the tendency of the global trade network of obtaining certain topological characteristics seem close to what we could call an endogenous drive. On top of this we have features that may be locked-in (see e.g. (Art89)).

What happens when we try to affect the emissions of carbon dioxide by controlling the carbon price? As John showed, the world is interconnected both universally (visualizing the world as connected functional subsystems) and particularly (visualizing it as connected specific activities), and so making a change that is designed to have a dramatic impact to one of its subsystems will be likely to have repercussions throughout the system. Now, the system is, as was argued, not likely to be all characterized by damping negative feedbacks. It is instead likely to display a whole range of features of dynamical systems that are a lot less reassuring and that on top of that are dramatic such as phase transitions, tipping points, hysteresis, historical path-dependency, etc; see e.g. (CAM$^+$05) for an introduction to chaos theory and dynamical systems.

Among the more widely cited problematic complex systems phenomena counts the concept of *tipping points*. At a tipping point, a system is brought from one equilibrium to another one that may be qualitatively much different. Due to time scale effects, the actual passage over a tipping point may itself be quite uneventful, and this is doubtless part of what is problematic and menacing about them: the system begins to shift relentlessly but at first imperceptibly from one state to the other and simply passing back may not reverse the situation. There are some well known suspected climatic tipping points and John listed as examples the loss of Arctic sea ice (decreasing the albedo of the planet), the loss of continental ice sheets (releasing large amounts of freshwater into the oceans) and the mobilization of high latitude methane stores. The latter effect is a joker in the deck as methane is a powerful greenhouse gas has that despite being much more short lived free in the atmosphere can nevertheless act to greatly accelerate global warming.

But there are also socioeconomic tipping points. John cited as examples combinations between: i) urbanization, energy costs and migration of food production; ii) population growth, climate change and water availability; iii) global connectivity and local inequality. All of these, as John argued, have potentially great ramifications and are far from being far-fetched.

Analyzing the structure of the global trade network, John concluded that it is far beyond the connectivity threshold. That is, removing connections at random, we must remove about 80% of the edges before the network becomes disconnected. Furthermore the structure of the network is one where the trade hubs are strongly interconnected, and this is the signature of an unstable network. The reason is that even transient problems in important nodes can have large effects on the whole network; as an example of this John mentioned the troubles with the gas pipeline from Russia running through the Ukraine that recently greatly affected the energy supply in the whole of Europe. The system, unsurprisingly when considering the criteria under which it continues to grow, is not adapted for resilience but for efficiency. Oscillations in the system can cause dramatic adverse effects with little advance warning as threshold values are suddenly passed; an example of this would be how recent spikes in food prices at once caused large segments of populations around the world to fall below the level where they could sustain themselves. Apart from the direct suffering caused by such events, they are also the stuff out of which political turmoil is made.

Finally, the Global Financial Crisis beginning in the autumn of 2008 may be best understood in terms of network dynamics. The proximate causes, such as miscalculation of risk, poor regulation, debt, asset ratios, general greediness and so on may actually mask underlying fundamental causes. Indeed, even if the agents would have acted ideally, the very topology and fundamental growth mechanisms of the network are likely to have made the system unstable in one way or the other in any case. The effects of the crisis in terms of trade intensity furthermore outdo the effects in GDP. It is estimated by the OECD that world trade will fall by 13% during 2009. This has a disproportionate effect on the poorest and most unequal countries and undermines support for globalization.

Connectivity, instability and inequality contains a number of dangerous paradoxes, summarized as follows by John:

– Current and growing world population levels cannot be maintained without a fully connected (globalized) world.

– This level of connectivity (almost) inevitably generates growing oscillations in availability of food, fuel and other necessities.

- Such oscillations impact larger fractions of the population in countries where wealth is more unevenly distributed – usually the poorest countries.
- These impacts can undermine support for globalization.
- However, those most impacted may be those that need it most.
- This dynamics is the backdrop against which other elements of the global system, that is biogeochemical change driven by economic activity driven by the aspirations of a growing population, play out today.

What to do? John stated that we need to mitigate climate change and other side-effects of economic activity to prevent far-reaching damage to ecosystems. We need to also make more people wealthier to halt and reverse population growth. At the same time we must feed an inevitably growing population while food production systems are affected by climate change and other damages.

But, we must do this against the background of how the system actually works. It is to be done in a system that is prone to growing oscillations but whose connectivity supports the world population; where fluctuating availability of necessities intersect with inequality to threaten the support for the globalization upon which present and future population levels rely. In a connected world, failure to address these problems has disastrous consequences, not just for those directly affected but for all of us. Addressing just part of the problem, e.g. climate mitigation, without taking account of the impacts of climate policy on other parts of the system is perilous.

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