“Optimal” climate change or structural change of the economy? A multi-agent model

Prof. Dr. Sylvie Geisendorf

ESCP Europe, Business School Berlin

Heubnerweg 8–10, D-14059 Berlin

Chair of Environment and Economics

sgeisendorf@escpeurope.eu

and

Competence Centre for Climate Change Mitigation and Adaptation (CliMA), University of Kassel

Preliminary Version, please do not quote

Abstract

Climate-economic models à la Nordhaus or Stern are based on macro-economic general equilibrium models to weigh costs of climate protection against costs of climate change. In essence, these models are standard neoclassical optimization models, resulting in a cost-minimizing climate policy; typically in a mix of some climate change with some protection measures. There are two problems with such an approach. First, it seems quite obvious that people in the real world do not behave as optimization models assume. Second, such models assume a rather static economy. There are some growth rates for technological progress, population or GDP, but these are either given exogenously or driven by investments which only affect one aggregate level of the economy. The paper suggests to explicitly consider behavioural aspects of climate policy. Instead of calculating optimal behaviour, the model depicts the consequences of different behavioural assumptions. And the model shall include the possibility of structural change.

Keywords: climate change, climate-economy models, multi-agent modelling, perceptions, bounded rationality, learning, structural change, mitigation

1 Introduction

Since the first attempts to combine natural science insights on the functioning of the climate system, with economic analyses of costs and benefits of climate change and of measures to prevent it (Rotmans 1990), and particularly since Nordhaus' (1994) first climate-economic model, such integrated assessment models became a broadly used tool in the discussion on climate change. Integrated assessment models (IAM) join data and projections from scientifc climate research with economic data and modelling techniques. By now, a considerable number of such models exist and continues to be developed (e.g Rotmans 1990, Nordhaus 1992, Peck/Teisberg 1993, Manne et al. 1994, Janssen 1997, Weber et al. 2005, de Bruin et al. 2007, Nordhaus 2008, Hope 2009). Most of them are intertemporal cost-benefit analyses, trying to assess the economic costs of damages from climate change or costs of its mitigation, and balancing them against benefits from economic output and damage prevention. Again, most of them do so with techniques borrowed from neoclassical growth theory, calculating an intertemporal optimum, as a function of a concise number of equations, describing economic output and climate behaviour. Nordhaus´ recent model e.g. consists of only 19 equations. The climate parts of these models, describing the impact of CO_2 emissions on atmospheric CO_2 concentration and the resulting expected temperature rise, are mostly taken from IPCC reports and some additional sources of climate science. The economic parts contain equations describing how economic output depends on technological progress, capital stock, and population, how savings determine consumption and investments in future capital stock, and how the output leads to CO_2 emissions (depending on energy intensity and the fraction of fossil fuels) and is in turn affected by the temperature rise they cause.

As the general flexibility of such climate-economic growth models in a narrower sense is restricted, some more recent studies try to broaden them into different directions, for example by including two types of climate protecting technical change driven by Learning-by-Doing versus Learning-by-Researching (Castelnuovo et al. 2005, Bosetti et al. 2006). In these models however, both learning processes are embedded in the traditional economic growth model and depicted as different drivers of technological progress, where Learning-by-Doing is implemented as a beneficial effect of conventional economic activity, and an optimal combination of both is derived.

But climate change is a long reaching problem. The intertemporal optimization therefore has to cover at least several decades, which is a difficult task for several reasons. The most discussed among them is the choice of an appropriate intertemporal discount rate, because, obviously, it influences the obtainable results quite a bit. The Stern review, claiming immediate and severe reduction of CO_2 emissions (Stern 2006), has been mostly criticized for its very low discount rate (Dasgupta 2007, Weitzmann 2007). But an even further reaching difficulty – and ultimate uncertainty – concerns the appropriate way to assess costs and benefits of technologies and actions lying in the far future and partially not even being invented yet (Weyant 2008).

Therefore, a growing number of papers discuss the implications of these and other uncertainties on the appropriate way to decide on political action. It has been argued correctly that the ex-ante derivation of an optimal climate change prevention path is an impossible task, although some authors argue that we should still use costs, benefits and predictions, as best they are known, to decide on suitable action (Schelling 2007). Others propose to use a different statistical probability distribution to account for possible higher climate sensitivities (Watson 2008).

But a lot of papers stress the magnitude of uncertainty in climate predictions, as well as in cost estimations, and point out the importance of learning and sequential decision making instead of one-shot optimization. Anda at al. (2008) try to show that a proper inclusion of uncertainty in cost-benefit analysis produces results in favour of flexible policy measures. Weyant (2008) suggests starting with low cost emission reductions, the feasibility of which is known today, even though they might not suffice to prevent enough emissions. Doing so would be doing more than we did thus far, because to date even the most modest suggestions derived from cost-benefit analyses have not been followed. Furthermore, implementing these techniques would allow for a learning process necessary to enable technicians and politicians to develop further instruments if needed.

Only a few papers explicitly address the impact uncertainty has on decisions making in climate contexts. One exemption is Baker (2004) with a game theoretic model, but in general the discussion revolves around the political implications of uncertainty, not around its impact on actual decision processes. As the bulk of climate-economic modelling continues to follow the optimization approach, which does not regard the way in which decisions are actually made, this is not surprising. But it might be useful to change or at least to supplement this modelling practice. Optimization models could at best – if they were based on precise data and knowledge – give an impression of what is possible to achieve maximally. But what truly happens depends on the actual decisions of relevant actors. However, as climate predictions and estimations of related costs and benefits are uncertain, it should be obvious that there is and will be no worldwide consent of a common climate policy to pursue. In fact, even the results of traditional optimization models reflect this discordancy, hence the diverging results and recommendations of different projects.

The current paper therefore suggests putting some effort into investigating the impact of personal (or institutional) beliefs on climate policy and the resulting climate change. A model having done so is the "battle of perspectives" model by Janssen (1996), presented in a more concise form in Janssen/deVries (1998). This multi-agent climate-economy model is based on the above described climate-economy equations, but instead of deriving an optimal solution, contains adaptive agents, controlling some of the parameters of the economic model. According to their personal perceptions of climate change and their general world view, the agents hold different beliefs on the importance of the climate crisis and on necessary action to take. The agents' perspectives range from a free-market advocate, over a risk conscious, scientifically informed agent, to a risk-averse environmentalist. In the model, they pursue their differing economic and environmental aims by controlling conventional investments and the transition from fossil fuels. In different scenarios, the authors investigate the impact of the agent's policy when placed in an environment corresponding or not corresponding to their convictions and what happens if they rule the world conjointly and learn from each other. In this paper, I argue that such models are important to demonstrate the long term consequences of wrong or delayed action in relation to the real world's behaviour. As much as it is true that we do not currently know exactly how severe climate change will affect the world economy, we should probably get an awareness of the risks of wrong (re)actions to it. Models like the one proposed here could help to shape such awareness.

A second concern of the paper is the way in which the economic system is depicted by general equilibrium models. Such models assume a rather static economy. There are growth rates for technological progress, population or GDP, but these are either given exogenously or driven by investments which only affect one aggregate level of the economy. The problem is that such models do not allow for a change of the economic structure. Investments in climate protection might not just be a cost but simply an investment in a future technology with promising growth rates and the potential to incite further growth in adjoining sectors. A world economic model reaching decades in the future should include such potential. Thus besides more realistic behavioural assumptions the model shall also include the possibility of structural change. The updated model shall be enabled to show how an economy can undergo structural change from within. Referring to a report by Jaeger et al. (2011), results from Acemoglu et al. (2011), and ideas going back to Fankhauser and Tol (2005) it shall be implemented how investments in climate protection can trigger growth in a particular sector of the economy – the “Green Economy” – which might, so the authors, offer a new growth path.

The “battle of perspectives” model shall be used to analyse how the original perspectives of the agents affect the chances of growth and climate protection if such a possibility is considered. Jaeger et al. (2011) conclude that a more ambitious CO_2 reduction goal of 30% instead of 20% until 2020 could enhance European investments and increase GDP by up to 6%. Now the “battle of perspectives” model shall be used to explore under what kind of behavioural assumptions that might be possible – and what happens for agents not believing in such a change.

The remainder of the paper is organized as follows: Part 2 gives an outline of the proposed climate-economic multi-agent model by Janssen (1996). Part 3 updates the input data on economic development, population, and ranges of expectations for climate sensitivity and damage costs. It presents some results of the original model and compares them with the update. Part 4 introduces the possibility of structural change of the economy triggered by investments into new technologies. Part 5 makes a case for the importance of multi-agent based research in climate economics. It also discusses at which points the assumptions of the model have to be questioned and altered. One such point is the observation that perceptions alone are not sufficient to take action. The paper concludes with part 5.

2 The battle of perspectives

Given the uncertainty about climate change and its impact on the economy, as well as about the costs of its potential prevention, it is only reasonable to recognize that relevant actors and institutions in politics and business do and will not agree upon a sole course of action to take. Even if the predictions of one of the optimization models were true – but how should we know, which one? – it is very unlikely that the collectivity of world decision makers will take the course derived as optimal action. Therefore, apart from continuing to work on the accuracy of climate models, as called for by Watson (2007) to reduce uncertainty on the scientific base of climate economic analyses, we should also work on how this persisting uncertainty affects climate policy. With “the battle of perspectives” Janssen (1996) and

Janssen/deVries (1998) proposed a multi-agent modelling approach. The core of the model consists of the well known macro-economic climate-economy approach, but some model parameters and variables are not given exogenously or determined by an optimization process, but controlled by the agents. They adjust these values according to their personal beliefs and their interpretation of the observed system behaviour. For one agent a temperature rise of 0.5° thus might not pose a problem while another takes it as a signal to cut economic growth to zero.

The world views or perspectives of the agents are based on the three most relevant of five types to cope with risk identified by the cultural theory of risk (Douglas/Wildavsky 1982, Wildavsky 2004). These are:

- The “Individualist”, believing in the power of free market forces and a great resilience of nature. He thinks that nature tends to equilibria, which, after perturbations, reinstall themselves. Thus, the individualist type is translated into an agent type believing that the climate-economic system will fix itself and economic activity should not be restricted.
- The “Hierarchist” is integrated into society and accepts its current regulations and state of scientific knowledge. He believes that nature can be exploited, but only within certain limits. His opinion is based on broadly accepted expert knowledge. In the climate-economy model hierarchists rely on IPCC best estimates and advocate for moderate restrictions to economic growth.
- The “Egalitarian” is a fundamental environmentalist and very risk-averse. He believes imbalances in the natural equilibrium will lead to disaster and thus requests to prevent any strong impact on nature. He rather lives on a very basic but equally distributed level of wealth than risk to disturb nature with a growing economy. In the model egalitarians opt for zero growth and high environmental protection.

Before elaborating on how these perspectives translate into specific beliefs and action in the model, let us sketch the climate-economic model itself.

2.1 The climate-economy model

The following climate-economy model has been taken from Janssen (1996) and Janssen/deVries (1998), who in turn based it on existing climate-economy models, like Nordhaus (1994) or Manne et al. (1994) and others. For more detailed information see Janssen (1996).

The model is a traditional macro-economic growth model, with an additional influence of the economy on climate (via emissions) and a feedback from climate to the economy (via economic losses due to climate change, or the costs of preventing it). Economic output of a single commodity Y is defined as:

$$Y(t) = cS(t) \cdot a(t) \cdot K(t)^{\gamma} \cdot P(t)^{1-\gamma} \tag{1}$$

where output depends on capital K and labour (proportional to population P), the rate of technological progress a and a weighted scale factor S accounting for damages due to climate change or reduction measures to prevent it (see equation 8).

Capital stock increases through investment I and depreciates with rate δ_K:

$$dK/dt = I \cdot Y - \delta_K \cdot K \tag{2}$$

The economy exerts an influence on climate by its emissions E, proportional to economic output and depending on an exogenously given, logistically declining energy intensity σ per output unit and on the transition M from fossil fuels to alternative energy sources, weighed by a coefficient α:

$$E(t) = \alpha M(t) \cdot \sigma(t) \cdot Y(t) \tag{3}$$

Emissions then contribute to atmospheric CO_2 concentration pCO_2, based on a carbon cycle model by Maier-Reimer/Hasselmann (1987):

$$pCO_2 = pCO_2(t_0) + \int_{t_0}^{t} 0.47 \cdot E(t) \left(c_1 + \sum_{i=2}^{5} c_i \cdot e^{\frac{\tau - t}{al_{i-1}}} \right) d\tau \tag{4}$$

The c_i are 5 fractions of carbon emissions, with $c_{i=2\text{ to }4}$ having different atmospheric lifetimes $al_{1\text{-}4}$. The multiplier of 0.47 has been introduced by Janssen to translate GT of atmospheric carbon in the original Maier-Reimer/Hasselmann model into atmospheric CO_2 concentration. This concentration now enters the calculation of radiative forcing (the difference between incoming and outgoing radiation energy in a climate system, measured in Watts per square meter), with ΔQ_{2xCO2} being the expected radiative forcing for a doubling of CO_2 concentration, taken from the IPCC report.

$$\Delta Q_{CO2}(t) = \frac{\Delta Q_{2XCO2}}{\ln(2.0)} \cdot \ln\left(\frac{pCO_2(t)}{pCO_2(t_0)} \right) \tag{5}$$

Radiative forcing is assumed to influence the global mean surface temperature, calculated in relation to the expected temperature change for a doubling of CO_2 (ΔT_{2xCO2}):

$$\Delta Tp(t) = \frac{\Delta T_{2xCO2}}{\Delta Q_{2xCO2}} \cdot \Delta Q_{CO2}(t) \tag{6}$$

As oceans take longer to warm up, this is just a potential increase, while the actual temperature increase lags behind by β=20 years:

$$\frac{d\Delta T}{dt} = \beta \cdot (\Delta Tp(t) - \Delta T(t)) \tag{7}$$

Finally, this temperature increase feeds back to economic output via the scale factor S, depicting the relation of abatements costs to damage costs. The b_i and θ_I are the scale and non-linearity of the cost, resp. damage functions:

$$S(t) = \frac{1 - b_1 \cdot (1 - M(t))^{b_2}}{1 + \theta_1 \cdot \Delta T(t)^{\theta_2}} \tag{8}$$

2.2 *The agents perspectives and their influence on the economy*

The climate-economy model is closed now. In traditional climate-economic cost-benefit analyses the parameters necessary to determine technological progress, expected radiative forcing, or costs and damages are estimated by the modellers and fed into the model as externally given. Now, the idea of the battle of perspectives model is to introduce the differing beliefs of relevant political institutions, by letting them determine these parameters according to their world views. Individualists[1] assume low climate sensitivity, low damage costs in case of climate change, a high rate of technological progress which is assumed to be less climate damaging by itself, and relatively high costs of potential additional climate protection measures. Hierarchists believe in medium costs and technological progress and IPCC best-estimates for climate sensitivity. Egalitarians think that climate sensitivity is high and also believe in high damage costs but, on the other hand, low contributions of technological progress and low mitigation costs.[2]

The thus individualized climate-economy models can, of course, not all represent the real world which can not be predicted accurately. What they do present in the model are the differing predictions of different actors or political institutions. These are important because everybody is likely to act in accordance with his own perception. In the whole modelling architecture these individual prediction models can now be matched with corresponding or not corresponding real world models (note that, of course, these have to be hypothetical as well, because of the fundamental uncertainty elaborated on above it is not obvious which scenario is more likely). Now it can be investigated how the supposed real world develops, if relevant political institutions have a realistic perception of it, and what happens if they do not.

In the model, all three types of agents have the same two possibilities to exert influence on the model economy. They decide about the amount of investments into traditional capital (I), which constitutes their attempt to control economic growth. And they decide about the transition speed from fossil to alternative fuels (M), which reflects their environmental policy. All types of agents do so following the same logic. They predict how the economy and the world temperature will develop according to their internal model and compare these data with the observation of the “real-world”. If their expectations are not fulfilled, they adjust their measures, but only slightly, remaining within the bounds of their deep routed beliefs. Individualists aim for continuous economic growth of at least 2% per year. If that is not realized they increase their investments according to the following rule, where I_I stands for investments of the Individualists and I for total investments of all types of agents:

$$\begin{aligned}
&I_I(t) = \min\left[1, \min[dY]\frac{I(t-1)}{dY(t-1)}\right], \forall\ dY(t) < \min[dY] \\
&and\ I_I(t) = I_I(t-1), \forall\ dY(t) \geq \min[dY] \qquad (9) \\
&with\ dY(t) = \frac{Y(t) - Y(t-1)}{Y(t-1)}
\end{aligned}$$

---

[1] The denominations of the original article have been kept here although they are not judged as very illustrative for the described groups. But they have been named thus in cultural theory and the comparability with the Janssen model should not get lost.

[2] The corresponding figures can be verified in table 2, placed in the next section, because it partly relies on updated data, explained there.

Due to their belief in climate robustness they opt for a very slow transition from fossil to regenerative fuels with a half-life time of 1000 years. They only adjust this if damage costs exceed a threshold of 1% of GDP, because that is supposed to endanger long term growth. Fossil fuel transition is then accelerated moderately. There is a lower bound of a half-life time of 20 years for this transition:

$$R_I(t) = 20 + (R_I(t-1) - 20) \cdot 0.99$$

Hierarchists aim at a stable economic growth (D[dY]) and stable investments and thus adjust their investments as a function of former investments and changes in economic growth:

$$I_H(t) = 0.9 \cdot I(t-1) + 0.1 \cdot \frac{D[dY]}{dY(t-1)} \cdot I(t-1) \tag{10}$$

They also try to avoid changes in temperature of more than 2° compared to 1900. If temperature rise is below 0.5°, they aim at a half-life time of 100 years for the transition from fossil fuels. If it temperature rises further, this transition is accelerated. Again, the fastest possible transition has a lower bound of 20 years half-life time:

$$\begin{aligned} R_H(t) &= 100, \ \forall\ M[\Delta T(t)] < 0.5 \\ R_H(t) &= 20 + (R_H(t-1) - 20) \cdot 0.995, \ \forall\ M[\Delta T(t)] > 0.5 \wedge M[\Delta T(t)] < 1 \\ R_H(t) &= 20 + (R_H(t-1) - 20) \cdot 0.99, \ \forall\ M[\Delta T(t)] > 1 \wedge M[\Delta T(t)] < 1.5 \\ R_H(t) &= 20 + (R_H(t-1) - 20) \cdot 0.98, \ \forall\ M[\Delta T(t)] > 1.5 \end{aligned} \tag{11}$$

Egalitarians aim at zero economic growth. They only invest to compensate for depreciation (δ_K) and aim for the most rapid possible transition to alternative fuels with a half-life time of 20 years:

$$I_E = \frac{\delta_k \cdot K(t-1)}{Y(t-1)} \tag{12}$$

The combined real-world/perspective scenarios can now be run over some decades to analyse, how wrong perspectives impinge on long term growth and climate development. But thus far the agents are not learning. They merely carry out their predefined behavioural rules. More interesting is a scenario closer to reality in which the world is ruled conjointly by a number of political institutions (or nations) with contradicting beliefs. In the model the actual policy is then calculated as the average of the proposed measures, weighed by the number of agents adhering to them. And the agents are allowed to learn from each other. They observe temperature development and compare it with their expectations. If the observations deviate only slightly from their prediction, they adjust their measures within the reach of their perspective. However, if the discrepancy surpasses a certain tolerance level, they have to acknowledge their world view seems not to fit. In that case, they compare their accuracy of prediction with those of other agents and possibly change their perspective, if another one seems to fit better. This part of the model has been implemented by a Genetic Algorithm (Holland/Miller 1991). Such algorithms are often used in Evolutionary Economics to depict learning.[3] They allow to compare different problem solutions with respect to some fitness criterion (here accurateness of prediction) and

[3] Arifovic (1991, 1994, 1995), Andreoni/Miller (1995), Birchenahll (1995), Dawid (1999), Geisendorf (2009).

adapt the solution with a likelihood to imitate better solutions relative to their performance. For a thorough description of the modelling details of Genetic Algorithms other sources should be consulted (e.g. Goldberg 1989, Mitchell 1997), but note that the algorithm here only works with full imitation not with a recombination of strategies.

It has to be acknowledged that in this simple form there is no political process going on when perspectives change. The model shall only illustrate how discrepancies between the conviction of political actors and the climate system's actual behaviour affect climate change, how, in such cases, the actors are not able to reach their own goals with the measures they have at hand when sticking to their convictions, and how time lags impact on the long term trajectory even if the actors are able and willing to learn. However, effects like international agreements or bargaining could be easily integrated.

3 The battle of perspectives 2.0

3.1 Input data

In this section the battle of perspectives model will be updated. The model and its data is more than 10 years old. Climate-economic dynamics deviate in several respects from the original model (table 1). Some figures, like expected temperature rise for a doubling of CO_2 have increased (IPCC 2007) others, like best estimates for losses due to temperature rise, have remained basically the same (Nordhaus 2008). Population estimates for 2100 seem to be rather high in the original model (Lutz et al. 2008). So are the highest loss expectations of the egalitarians that are considerably over the highest scenarios of the recent Stern Report (Stern 2007), which in turn has been criticized for its too dramatic position. And last but not least, after having declined in a first period, CO_2 emissions increased by 2,3% in the period between 2000 and 2006 (UNFCCC 2008).

	Janssen (1996)	**Updated**
General data		
World population 2100	11,3 Milliarden	8-9 Milliarden
CO2-Emissions	Strong reduction till 2000	2000-2006 2,3% growth
Radiative forcing W/m2 for 2xCO2	4.3	3.7
Individual expectations		
Expected temperature rise for doubling of CO2	Min = 0,5° Best estimate = 2,5° Max = 5,5°	Min = 1,5° Best estimate = 3° Max = 7,7°
Economic losses for +3°	{0%, 1,3%, 32%} of world GDP	{1,5%, 3%, 20%} of world GDP

Table 1: Original and updated input data for climate model and personal beliefs

In the present paper the model as well as the agents' perspectives have been updated with current knowledge. Whereas climate-economic dynamics deviate in several respects from the original model, the agents' perspectives are still quite valid and only have to be altered, where new data suggests an update of information within the given beliefs. This is the case for estimates on climate sensitivity and damage costs. Table 2 gives the corresponding parameters, used to individualize the above equations.

	Individualist	**Hierarchist**	**Egalitarian**
Climate Sensitivity			
ΔT_{2CO2}	(0.5) 1.5	(2.5) 3	(5.5) 7.7
Damage costs			
θ_1	(0) 0.00166	(0.0014) 0,0011	(0.004) 0.0025
θ_2	(0) 2	(2) 3	(4) 4
Technological development			
δ_a	0.04[4]	0.012	0.002
Mitigation costs			
b_1	0.25	0.11	0.05
b_2	3.5	2.9	2.3
δ	0.4	0.5	0.6

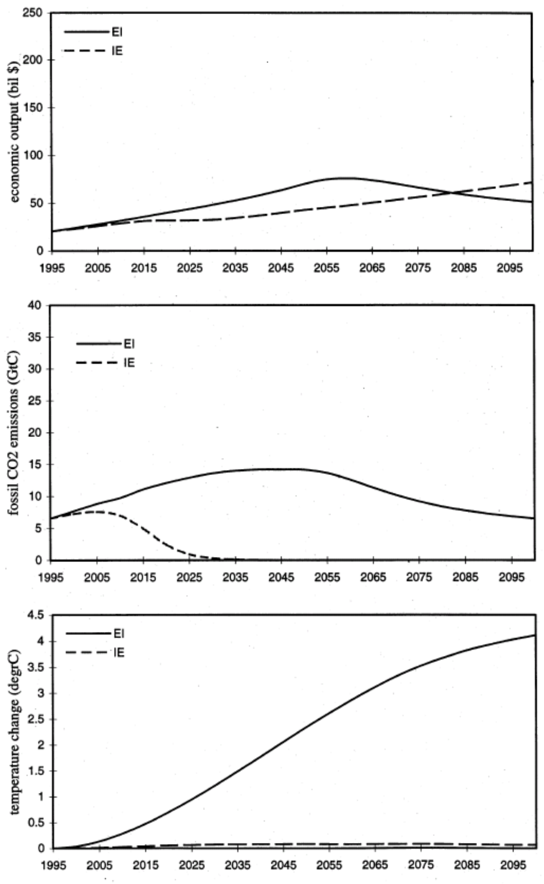
Table 2: Original and updated parameters for personal beliefs and strategies (original data taken from Janssen 1996, p. 209 and put into parentheses when they have been updated)

In general, the perspectives are still quite in agreement with present work on the effect of uncertainty about climate change. Uncertainty is likely to shape not only the intensity but also the type of reaction, according to individual beliefs (Watson 2008). Agents believing in a dramatic rise of temperature are likely to favour mitigation whereas individualists believing in moderate change will favour adaptation which is basically implemented in the model.

3.2 Results

The results of the original model are broadly discussed and illustrated in Janssen (1996) and Janssen/deVries (1998). Let us just pick out a few to illustrate how the model can be used and what kind of results are to be expected. These will be compared with the results for the model update to investigate the effect of changed scientific knowledge and of changed initial conditions because climate change has been going on since.

[4] This value has been corrected, as the original value of 0.004 must be a mistake.



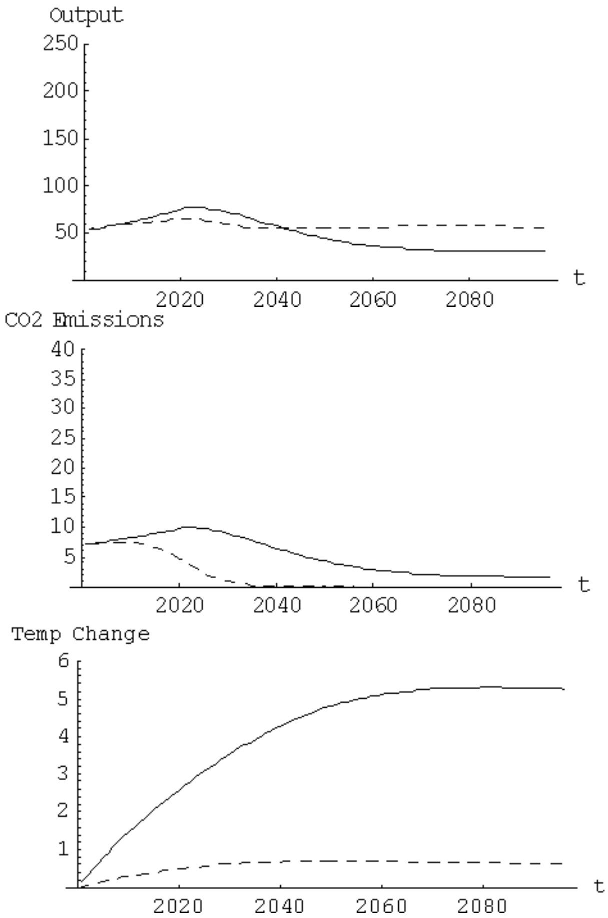


Fig. 1 Economic output, CO_2 emissions and temperature change for individualists in a vulnerable environment (EI) and environmentalists in a robust environment (IE). Source: **Janssen 1996: 56**

Fig. 2 Economic output, CO_2 emissions and temperature change for individualists in a vulnerable environment(EI) and environmentalists in a robust environment (IE). **Results of the author**

In a first experiment, agents with a perspective representing one of the extremes were placed in environments working according to the opposite extreme. A free-market advocate was thus placed in a vulnerable environment and an environmentalist in a very robust nature. Fig. 1 depicts the consequences in Janssen´s model, fig. 2 in the update. The original simulation started 1995 and went till 2100. The update starts in 2000 and also goes to 2100. Initial values for capital stock, labour force and climate data, as well as population projections are based on contemporary data on the world economic situation and climate models. The fictitious real-world scenarios correspond to one or the other opposite perspectives respectively. The model does not claim to represent one or the other most likely scenario, but it helps to analyse what happens if climate policy is very inadequate for the actual situation and only slightly corrected over time. The policy corrections within both world views are quite restrained and result in only moderate influences of the climate-economy system. Individualist politicians let temperature rise by 4° in Janssen’s model and 5.3° in the update and have to live with the resulting economic losses. Environmentalist politicians are better of in the end, but unnecessarily renounces to possible economic growth in this stable environment.

Comparing the scenarios we see that total world output in 2000 (the starting point for the update) has risen more than expected in the original model, so model 2.0 starts from a higher output level. But following a period of growth, the individualist's output decreases more than in the old version and the environmentalist's output stabilizes. Looking at the higher temperature change we would expect that to be the reason for the economic decline. However, sensitivity runs have shown that the higher climate sensitivity and damage costs (feeding temperature rise back to the economy) did not have a major impact on output. The general shape of the output curves in the update is caused by the population projection. In contrast to Janssen's assumption of a continuously rising population, IIASA's medium world population projection estimates a decline of population in the last decades of the century (Lutz et al. 2008). Emissions and resulting temperature increase just follow this trend. It is probably worth mentioning that temperature rise would have been even larger than it already is if the more pessimistic population figures had been used.

A first result thus indicates that population figures are much more important for economic activity and resulting climate change than an update of personal beliefs to current scientific knowledge – provided the agents stay within the bounds of their general world view. Updating ones beliefs within these bounds means, for example, that individualists still use optimistic assumptions about temperature rise and damage costs, but accept that minimum estimates for these are higher than they were 14 years ago which is a plausible assumption.

Now let's switch to learning. The model world is no longer ruled by only one type of agent. 50 agents, representing relevant decision institutions like governments populate the model world and rule it conjointly. Again, initially the majority of agents adhere to a perspective at the opposite end of the actual climate dynamics, but there are small initial percentages of the correct and the intermediate (hierarchist) world views. In comparison with fig. 1 and 2 we see that the initially resembling time paths now change to more adequate policies, reflected in a better exploitation of the robust system or a lower rise of emissions and temperature in the vulnerable environment (fig. 3 and 4).

However, what is interesting, apart from this observable learning effect, are the problems arising from initial misperceptions and the time it takes to correct them. In a way the proposed scenarios underlying fig. 3 and 4 are quite optimistic in that they allow for immediate learning when expectations are not fulfilled. Compared to real world climate policy this seems quite ambitious, as current data on rising CO_2 emissions suggest that politicians do not even stick to their own proclaimed intentions fixed in the Kyoto protocol.[5] Weyant (2008) pointed out that thus far even the least ambitious propositions for climate protection, advocated by reports like Nordhaus (1994) who has been largely criticized for underestimating the problem, have not been carried out. But even if learning and adaptation takes place, starting with the wrong policy is a long lasting cutback, because learning takes time. Initially too low investments or too high emissions impinge on future development chances for decades to come. For example, temperature increase for the initially too market oriented world governance reaches around 2.5° versus less than 1° if the correct policy is installed from the beginning on. Economic

[5] However, the financial and resulting economic crisis might now result in a fulfilment of the reduction commitments, but only due to reduced economic activity.

output, on the other hand, could have been 1/3rd higher by 2100 if the robust environment had been ruled by individualists from the beginning on (the comparisons were made with Fig. 3 in Janssen 1996: 55).

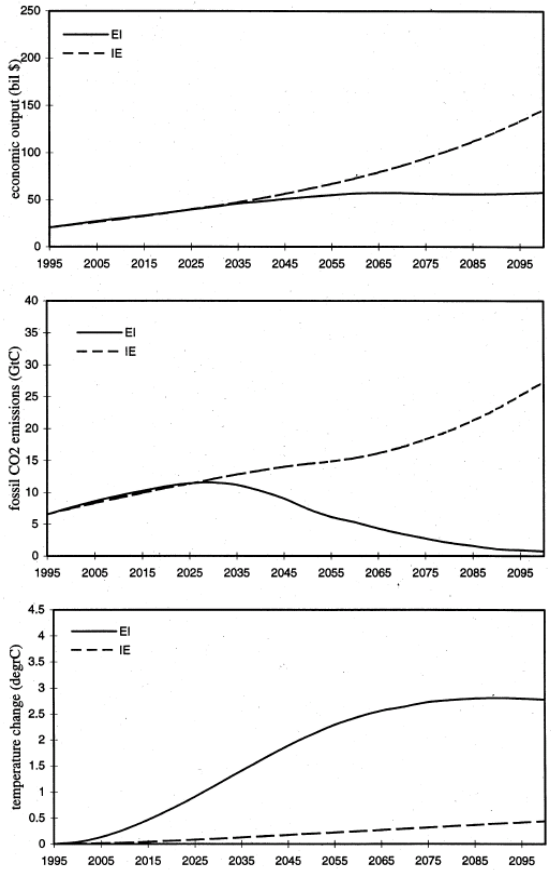


Fig. 3 Economic output, CO_2 emissions and temperature change for an initial majority of individualists in a vulnerable environment (EI) and an initial majority of environmentalists in a robust environment (IE). Source: **Janssen 1996: 61**

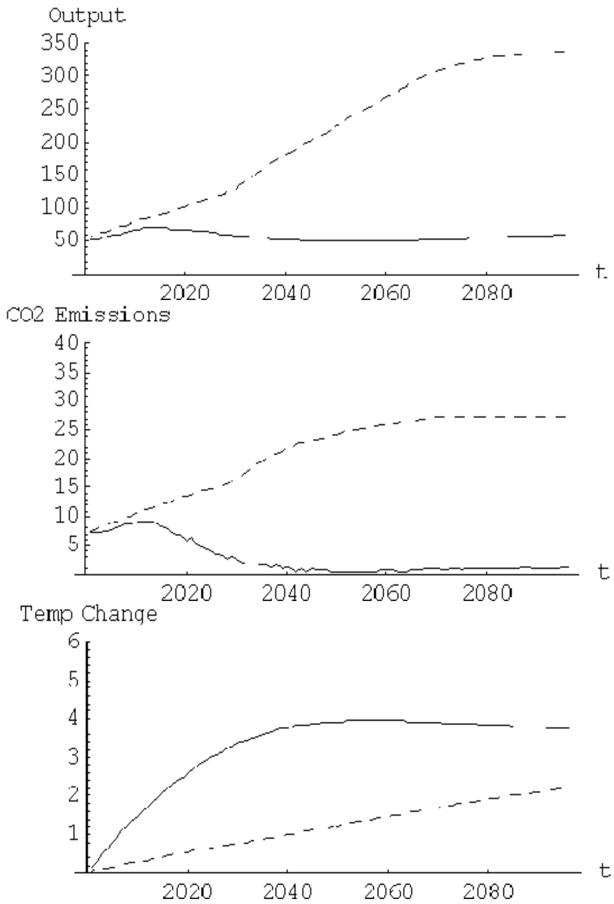


Fig. 4 Economic output, CO_2 emissions and temperature change for an initial majority of individualists in a vulnerable environment (EI) and an initial majority of environmentalists in a robust environment (IE). **Results of the author**

Again, the main difference in the shape of the curves between Janssen's model and the update (exponential growth versus stagnation on a high level for output and emissions) is caused by the population projections. The higher temperature increase in the update, for agents living in a robust nature (dotted lines), is caused by a higher estimation of climate sensitivity. However, in this robust nature even higher damage cost assumptions than in the original model do not impinge much on profits. The individualistic strive for fixed economic growth rates per capita, starting from a higher initial capital stock, thus results in much higher output.

4 Optimizing climate change or changing the economy?

Sorry, still under construction - This part of the paper will be written until the conference.

5 Why we need such models

The main contribution of agents-based climate-economy models, like the one sketched above, is the creation of an awareness for the effect of perceptions on climate policy. The way climate change is perceived by relevant actors or institutions determines climate policy. “There is, in short, no `climate change´ outside of a socially constructed framework” (Jordan/Riordan 1997: Abstract before page 1). The exemplary model results illustrate how substantial the impact of wrong or belatedly corrected perceptions can be on the long run climate-economic development. A late recognition of a too optimistic point of view e.g. entails the danger of long lasting consequences in the form of rising temperature and economic damages. This is not saying that the corresponding scenario with a very sensitive environment is the most likely or that we should take immediate action because it might be. Among other things, the model is too simplistic to derive such recommendations from it. It has to be noted however, that the climate-economy part is an only slightly simplified version of the corresponding parts of current intertemporal optimization models, trying to generate such recommendations. So the debatable part is mostly the way the perceptions, the derived actions, and the learning process have been modelled.

Let us have a brief lock at these points. The perceptions are based on the three relevant types of attitudes towards risk, found by the cultural theory of risk. Its insights and typology are still valid today (Wildavsky/Sweditorlow 2005). Of course, it might be debated whether the types have been translated correctly into the model’s perspectives, but on balance they seem to represent good fits. However, the problem of current international climate policy seems not to depend on such perceptions alone. Judging from recent surveys in the European Union, 62% of the citizens are convinced that climate change is the second most pressing issues of the world (right after poverty and food and water scarcity) (Europäische Kommission 2008). The problem perception agreed upon in the world governments seems to fit largely with the scientific knowledge of the IPCC reports and thus with the hierarchist type of agent described above. But actual climate protection actions lag far behind the measures taken by the corresponding agents in the above model. Janssen (1996) and Janssen/deVries (1998) did not consider reasons for institutions or governments to fall behind their proclaimed convictions about necessary abatement measures. Yet in international negotiations these are plenty. Climate stability is the most exemplary common good and thus associated with the typical provision and maintenance dilemma. Even agents convinced of an immediate pressure for action might refrain from it because of the marginal impact of their isolated measures or because of distributional and justice issues. The actual willingness to act is largely dependent on the behaviour of the other actors. This is likely to result in less action than could be expected from the perspectives alone. Even actors who are convinced of climate change dangers will only renounce to short term profits if others do so as well. That should be considered in the model. A second point, regarding the modelling of the agents´ activities, concerns the quite simplistic way in which actions are taken in the model. The agents have only two ways to influence climate policy and rely on only one indicator of success. It should be analyzed whether more sophisticated control and intervention schemes, would alter the findings. As a first guess it can be expected that real learning processes will be slower than the ones depicted in the model which will underline the even higher need to acknowledge the resulting delays in climate policy.

Obviously, the way the agents learn gives only a crude picture of actual learning processes. However, what they show is the extent to which such an adaptive process can slow down change to a more appropriate policy and corresponding results. But having said so, we should be aware that the depicted process is even quite ambitious because the agents are willing to learn and adopt better adapted world views. Empirical studies like Leiserowitz (2006) on US American perceptions of the climate problem and the currently rising CO_2 emissions suggest that learning might even be much slower in reality. A possible next step in agent-based climate-economy modelling therefore might be to calibrate the model to such observations in order to start from a realistic climate policy. As Weyant (2008) pointed out, thus far, even the least ambitious propositions for climate protection have not been carried out. Taking this seriously implies that the world population seems to pursue a very much "individualistic" kind of strategy (in the sense of the above described optimistic perception) although – as has been pointed out above – their proclaimed perceptions might be more "hierarchist".

Although such a simple model can not be used to predict climate policy accurately, it is likely to draw a more realistic picture of what kind of political action is possible at all, considering the willingness to act of the relevant political institutions. It can be assumed that, if the shares of the different political types are initialized on the basis of empirical data, the resulting climate policy is at least more realistic then the optimization path of traditional climate-economic models, because obviously, "Optimal climate policy is a utopia" (van den Berg 2004, p. 385). The role of uncertainty and learning for climate policy is discussed in parts of the literature (Finus/Pintassilgo 2009) to models to analyse it are largely missing. Therefore, the current paper suggests putting more effort into making models like the one presented here more precise and using them to analyse the importance of perceptions of political actors on climate policy. In other areas of ecological-economic interaction the discussion on the importance and possibilities of more realistic representations of economic agents has gone on since the original Janssen model has been published.[6] But the issues debated there are mostly from the domain of harvesting common pool resources (Deadman 1999, Little/McDonald 2007) like fish (Dreyfus-León/Kleiber 2001) or water (Becu et al. 2003) or rangeland management (Janssen et al. 2000). The discussion on integrated climate-economic models could draw on these insights.

6 Conclusions

Climate-economic modelling continues to revolve around Nordhaus' (1994) macroeconomic general-equilibrium model, in which responses to climate-change are assumed to be optimal. Such an approach is far from grasping the actual complexity of human behaviour. As predictions about climate change are uncertain, policy relevant institutions hold different beliefs about how critical the situation actually is and how much climate change prevention is necessary and will cost. The literature increasingly discusses the relevance of uncertainty and uses it to make a case for flexible policy

[6] Van den Berg/Gowdy 2000, Bousquet/Page 2004, von den Berg 2007, and a whole special issue of Ecological Economics on "The human actor in ecological-economic models".

instruments and sequential decision making. But uncertainty about the dynamics and implications of climate change is not only important for the boundary conditions of economic decisions; it reflects itself in the way these decisions are made.

Therefore, in addition to intertemporal climate-economic cost-benefit models, trying to derive an optimal climate policy, the explicit depiction of the impact of uncertainty on actual political decisions would be desirable and useful. An optimal policy, even if it could be derived from a model, is only as good as it is followed. However, contemporary emission increases, the failure to implement even the least severe recommended action and empirical studies on climate change risk perceptions imply that we are likely to be far from adopting such an optimal policy, even for a moderate sensibility of the environment. Models, like the above proposed could help to illustrate the consequences of such behaviour.

The paper suggests to put more effort into agent-based models in climate economics. As a first step, the original Janssen (1996) model has been updated with current data, to investigate how much the outcome changes thereby. It has been shown that integration of new data within the given perspectives has less influence on the model outcome than might first be expected. The main change in the qualitative form of the time paths only results from population projections, not from variations of individual parameters for climate sensitivity or damage costs. The model is thus quite robust in changes of most of its parameters which is an interesting result in itself.

In further steps it should now be tried to develop more empirically based representations of the agents' perceptions and of their actual behaviour. The management of climate change being a typical common good dilemma suggest that believing in its dangers is not enough to engage in preventive action. That should be considered in further model versions.

References

Anda, J., Golub, A., Strukova, E. 2009, Economics of climate change under uncertainty: Benefits of flexibility. Energy Policy 37(4): 1345-1355

Acemoglu, D., Aghion, P., Burzstyn, L. and Hempous, D. 2011, The Environment and Directed Technical Change, The Amerian Economic Review 102(1): 131-166

Andreoni J, Miller J (1995) Auctions with Artificial Adaptive Agents. Games Econ Behav 10: 39-64

Arifovic J 1991, Learning by genetic algorithms in economic environments. Doctoral dissertation, University of Chicago

Arifovic J 1994, Genetic algorithm learning and the cobweb model. J Econ Control 18: 3-28

Baker, E. 2004, Uncertainty and learning in a strategic environment: global climate change. Resource and Energy Economics 27(1): 19-40

Becu, N., Perez, P., Walker, A., Barreteau, O. and Le Page, C., 2003, Agent based simulation of a small catchment water management in northern Thailand: Description of the CATCHSCAPE model, Ecological Modelling 170(2-3): 319-331

Birchenhall C 1995, Modular Technical Change and Genetic Algorithms. Comp Econ 8: 233-253

Bosetti, V., Carraro, C. and Geleotti, M., 2006, Stabilisation Targets, technical Change and the Macroeconomic Costs of Climate Change. CIP –Climate Impacts and Policy Division Working paper N. 03.2007

Bousquet, F. and Le Page, C., 2004, Multi-agent simulations and ecosystem management: a review, Ecological Modelling 176(3-4): 313-332

Castelnuovo, E., Galeotti, M., Gambarelli, G. and Vergalli, S., 2005, Learning-by-Doing vs. Learning by Researching in a model of climate change policy analysis. Ecological Economics 54: 261-276

Dawid H (1999) Adaptive Learning by Genetic Algorithms: Analytical Results and Applications to Economic Models. 2nd revised and extended edition, Springer, Berlin

Deadman, P.J., 1999, Modelling individual behaviour and group performance in an intelligent agent-based simulation of the tragedy of the commons, Journal of Environmental Management 56: 159-172

de Bruin, K.C., Dellink, R.B. and Tol, R.S.J. 2007, AD-DICE: An Implementation of Adaptation in the DICE Mode. Fondazione Eni Enrico Mattei Working paper 2007.51. http://www.feem.it/NR/rdonlyres/94DFCDFF-82D6-4D64-A1B7-9B164FAA143/2343/5108.pdf

Douglas, M., Wildawski, A. 1982, *Risk and Culture*: An Essay on the Selection of Technological and Environmental Dangers. Berkeley, University of California Press

Dreyfus-leon, M., and Kleiber, P., 2001, A spatial individual behaviour-based model approach of the yellowfin tuna fishery in the eastern Pacific Ocean, Ecological Modelling 146: 47-56

Ecological Economics, 2004, Special Issue: The human actor in ecological-economic models, Ecological Economics 35

Europäische Kommission 2008, Einstellungen der europäischen Bürger zum Klimawandel. Befragung: März – Mai 2008, Spezial Eurobarometer 300. http://ec.europa.eu/public_opinion/archives/ebs/ebs_300_full_de.pdf

Fankhauser, S. and Tol, R.S.J. 2005, On Climate change and economic growth, Resource and Energy Economics 27: 1-17

Finus, M. and Pintassilgo, P., 2009, The Role of Uncertainty and Learning for the Success of International Climate Agreements, Stirling Economics Discussion Paper 2009-16

Geisendorf, S. 2009, The Influence of Innovation and Imitation on Economic Performance. Econ Issues 14(1): 65-94

Goldberg, D.E., 1989, Genetic Algorithms in Search, Optimization and Machine Learning. Addison-Wesley, Reading

Holland, J.H., Miller, J.H., 1991, Artificial adaptive agents in economic theory. The American Economic Review, 81: 365-370

Hope, C.W. 2009, How deep should the deep cuts be? Optimal CO_2 emissions over time under uncertainty. Climate Policy, 9: 3-8

IPCC, 2007, Climate Change 2007: Synthesis Resport. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate change (Core writing team: Pachauri, R.K. and Reisinger, A. (eds.)), IPCC, Geneva, Switzerland.

Jaeger, C., Paroussos, L., Mangalagiu, D., Kupers, R., Mandel, A. and Tàbara, D. 2011, A New Growth Path for Europe. Generating Prosperity and Jobs in the Low-Carbon Economy. Report for the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

Janssen, M.A., 1996, Meeting Targets: Tools to Support Integrated Assessment Modelling of Global Change. PhD Thesis ISBN 90-9009908-5, University of Maastricht, the Netherlands.

Janssen, M.A. 1997, Optimization of a non-linear dynamical system for global climate change. European Journal of Operational Research, 99: 322-335

Janssen, M.A. and de Vries, B., 1998, The battle of perspectives: a multi-agent model with adaptive responses to climate change. Ecological Economics, 26: 43-65

Janssen, M.A., Walker, B.H., Langridge, J. and Abel, N., 2000, An adaptive agent model for analysing co-evolution of management and policies in a complex rangeland system, Ecological Modelling 131:249-268

Jordan, A. O´Riordan, T. 1997, Social Institutions and Climate Change: Applying Cultural Theory to Practice. CSERGE Working Paper GEC 97-15

Kupers, R. and Mangalagiu, D. 2010, Climate Change Policy: Positive or Negative Economic Impact? Why? ECF Working Paper 1/2010.

Leiserowitz, A. 2006, Climate change Risk Perception and Policy Preferences: The Role of Affect, Imagery, and Value. Climatic Change, 77: 45-72

Little, L.R. and McDonald A.D., 2007, Simulations of agents in social networks harvesting a resource, Ecological Modelling 2004: 379-386

Lutz, W., Sanderson, W. and Scherbov, S., 2008, IIASA's 2007 Probabilistic World Population Projections. IIASA World Population Program Online Data Base of Results 2008, http://www.iiasa.ac.at/Research/POP/proj07/index.html?sb=5

Manne, A.S., Mendelsohn, R., Richels, R.G., 1994. MERGE: A model for evaluating regional and global effects of GHG reduction policies. In: Nakicenovic, N., Nordhaus, W.D., Richels, R., Toth, F.L. (Eds.), Integrative Assessment of Mitigation, Impacts, and Adaptation to Climate Change. 143–172, CP-94-0, IIASA, Laxenburg, Austria.

Meier-Reimer, E. and Hasselmann, K. 1987, Transport and storage of CO_2 in the ocean – an inorganic acean-circulation carbon cacle model. Climate Dynamics, 2: 63-90

Mitchell, M., 1997, An Introduction to Genetic Algorithms. 3rd edition, MIT Press, Cambridge

Nordhaus, W.D., 1994, Managing the Global Commons: The Economics of Climate Change. Cambridge, MA: MIT Press

Nordhaus, W.D., 2008, A Question of Balance Weighing the Options on Global Warming Policies, Yale University Press New Haven & London

Peck, S.C., Teisberg, T.J., 1992, CETA: A Model for Carbon Emission Trajectory Assessment. The Energy J., Vol. 13, No. 1.

Schelling, T.C. 2007, Climate change: The Uncertainties, the Certainties, and What They Imply About Action. Economist's Voice, July 2007

Rotmans, J. 1990, IMAGE: An Integrated Model to Assess the Greenhouse Effect. Ph.D. thesis, Kluwer Academic Publishing, Dordrecht, The Netherlands

Stern, N., 2007, The Economics of Climate Change: The Stern Review. Cambridge, Cambridge University Press.

UNFCCC, 2008, Rising industrialized countries emissions underscore urgent need for political action at Poznan (18.11.2008). http://www.co2-handel.de/article310_10287.html

Watson, A.J., 2008, Certainty and Uncertainty in Climate Change Predictions: What Use are Climate Models? Environmental and Resource Economics, 39: 37-44

Rotmans, J. 1990, IMAGE: An Integrated Model to Assess the Greenhouse Effect. Ph.D. thesis, Kluwer Academic Publishing, Dordrecht, The Netherlands

van den Bergh, J.C.J.M., 2004, Optimal climate polica is a utopia: from quantitative to qualitataive cost-benefit analysis, Ecological Economics 48: 385-393

van den Bergh, J.C.J.M., 2007, Evolutionary Thinking in environmental economics, Journal of Evolutionary Economics, 17: 521-549

van den Bergh, J.C.J.M. and Gowdy, J.C. 2000, Evolutionary Theories in Environmental and Resource Economics: Approaches and Applications, Environmental and Resource Economics, 17(1): 37-57

Weber, M, Barth, V. and Hasselmann, K. 2005, A multi-actor dynamic integrated assessment model (MADIAM) of induced technological change and sustainable economic growth. Ecological Economics, 54: 306-327

Weyant, J.P. 2008, A Critique of the Stern Review's Mitigation Cost Analyses and Integrated Assessment. Review of Environmental Economics and Policy, 2(1): 77-93

Weitzmann, M.L. 2007, The Stern Review of the economics of climate change. Journal of Economic Literature 45(3): 703–724

Wildawski, A., Sweditorlow, B. (ed.) 2005, Cultural Analysis: Politics, Public Law, and Administration. Piscataway: Transaction Publishers