The impact of personal beliefs on climate change: A multi-agent climate-economic model

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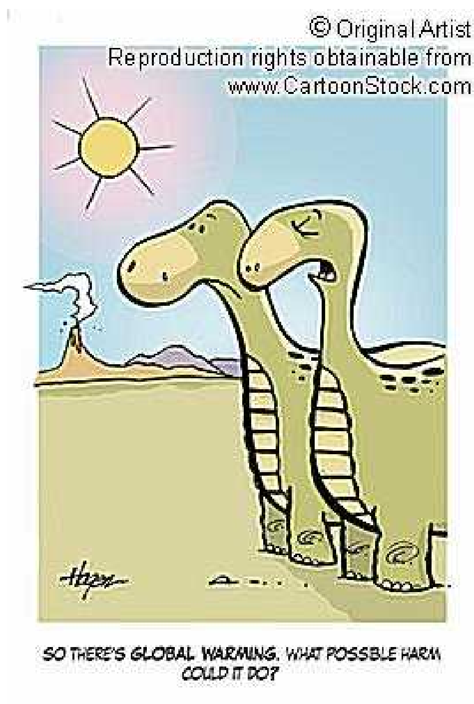

Abstract

Climate-economic models are mainly intertemporal cost-benefit analyses, trying to balance the damages from climate change against mitigation costs and derive an optimal climate policy. In recent years, the huge importance of uncertainty about climate behaviour, impinging such models, has been emphasized and it has been argued that one-shot intertemporal optimization is an impractical venture. However, only few authors tried to explicitly model the impact of uncertainty on agents' beliefs and resulting behaviour. Jansson (1996) is a notable exception, who developed a multi-agent climate-economy model. Based on a macro-economic climate-economy model, he implemented adaptive agents, holding different perspectives on the dynamics of climate change and necessary preventive action. The paper aims to make a case for this largely unnoticed model, for more research into this direction and for an update of the model with current data, to help analysing the importance of human beliefs and the significance of uncertain data for the realisation of climate protection.

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

1 Introduction

Since the first attempts to combine natural sciences 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 principal leeway of such climate-economic growth models in a narrower sense is restricted, more recent studies try to broaden them into different directions, e.g. 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 reach at least over 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 available or 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 rightly argued 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 prod to the importance of learning and sequential decision making, instead of on-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 even the most modest outcomes of cost-benefit analyses suggested and thus constitute a start. Furthermore, implementing these techniques would allow for a learning process, necessary to enable technicians and politicians to develop further instruments if needed.

Only few papers explicitly address the impact uncertainty has on the decisions of relevant human actors. One exemption is Baker (2005) 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 world consensus about a common climate policy to pursue. In fact, even the results of traditional optimization models reflect this discordancy, hence he diverging results and recommendations of different projects.

The current paper therefore suggests putting some effort into investigating of the impact of personal (or institutional) beliefs on climate policy and the resulting climate change. The only model having already done so, I know of, is the “battle of perspectives” model, by Jansson (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.

The remainder of the paper is organized as follows: Part two gives an outline of the proposed climate-economic multi-agent model by Jansson (1996) and part three presents and comments on some of its results. Part four makes a case for the importance of such models and more research in that direction. The paper concludes with part five.

2 The battle of perspectives

Given the huge uncertainty about climate change and its impact on the economy, as well as about the costs of its eventual 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. 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 still persisting uncertainty affects climate policy. Jansson (1996) and Janssen/deVries (1998) proposed a multi-agent modelling approach, named "the battle of perspectives", to do so. The core of the model still 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 thus 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 our capitalist 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 Jansson (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 Jansson (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 by:

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

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 equ.8).

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

$$dK/dt = I \cdot Y - \delta_K \cdot K \qquad (2)$$

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:

$$E(t) = \alpha M(t) \cdot \sigma(t) \cdot Y(t) \qquad (3)$$

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

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

The c_i are 5 fractions of carbon emissions, with $c_{i=2\text{ to }4}$ having different atmospheric lifetimes al_{1-4}. The multiplier of 0.47 has been introduced by Jansson to translate GT of atmospheric carbon in the original Maier-Reimer/Hasselmann model into atmospheric CO_2 concentration. This concentration now enters the determination 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.

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

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}):

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

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

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

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_l are the scale and non-linearity of the cost, resp. damage functions:

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

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. The idea of the battle of perspectives model now is to introduce the differing beliefs of relevant political institutions, by letting them determine these parameters according to their world views. Individualists 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.

These individualized climate-economy models can, of course, not all represent the real world, which, unfortunately, none of us can predict accurately. What they do present in the model, are the differing predictions of different actors or institutions. They are important, because everybody is likely to act in accordance with his own view. 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, the modeller is not to decide which scenario is more likely). Now it can be investigated, how the supposed real world develops, if relevant 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), constituting their supposed control of economic growth. And they decide about the transition speed from fossil to alternative fuels (M), constituting 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%/year and adjust their measures, if damage costs exceed a threshold of 1%/GDP, because that is supposed to endanger long term growth. Hierarchists take temperature rise as a problem indicator and start to adjust their measures if it exceeds 0.5°. Egalitarians aim at zero economic growth. They only invest to compensate for depreciation and aim for the most rapid possible transition to alternative fuels (Jansson 1996 and Jansson/deVries 1998). 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.

More interesting is a closer to reality scenario, in which the world is ruled conjointly by a number of institutions 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. If 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 an algorithm allows to compare different problem solutions with respect to some fitness criterion (here accurateness of prediction) and adapts the solution, with a likelihood to imitate better solutions, relative to their performance.

3 Some results

The results of the model are broadly discussed and illustrated in Jansson (1996) and Janssen/deVries (1998). Let me just pick out a few to illustrate how the model can be used and what kind of results are to be expected. 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. The simulations started 1995 and went till 2100. Initial values for capital stock, labour force and climate data, as well as population projections were based on existing 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 thus 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.

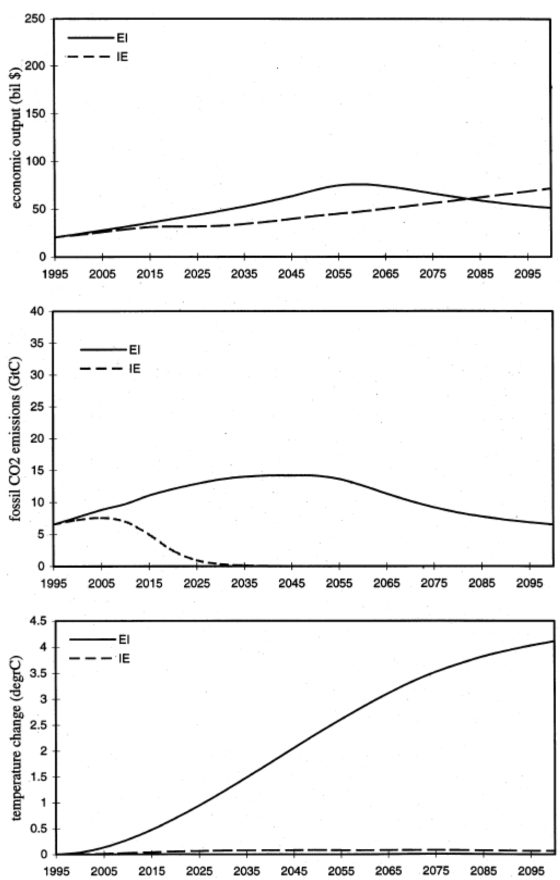

Fig. 1 Economic output, CO_2 emissions and temperature change for individualists in a vulnerable environment (EI) and environmentalists in a robust environment (IE). Source: Jansson 1996: 56

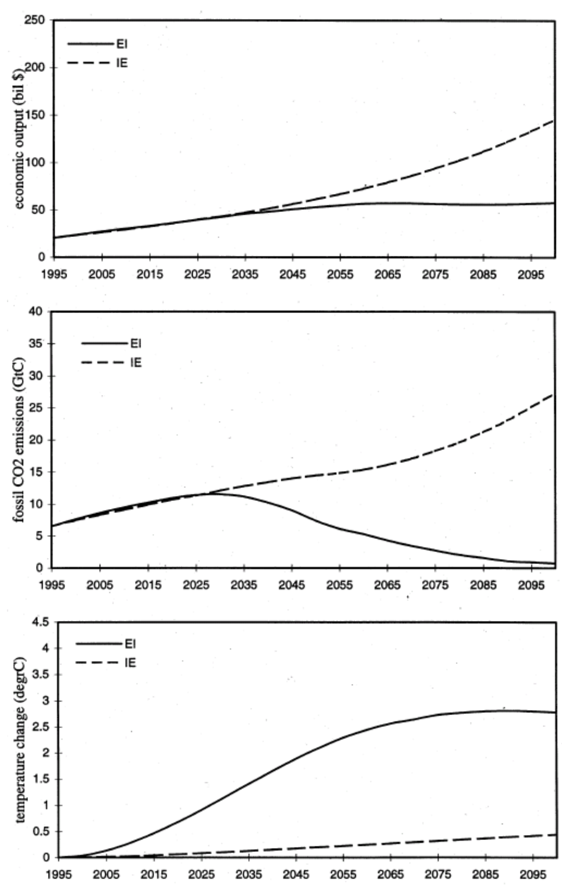

Fig. 2 Economic output, CO_2 emissions and temperature change for an initial majority of individualists in a vulnerable environment (EI) and an initial majority of environmentalists in a robust environment (IE). Source: Jansson 1996: 61

As can be seen, the policy corrections within both world views are quite restrained and result in only moderate influences of the climate-economy system. The individualist lets temperature rise by 4° and has to live with the resulting economic losses, whereas the environmentalist is better of in the end, but unnecessarily renounces to possible economic growth in this stable environment.

Fig. 2 depicts some learning scenarios. The world is ruled by 50 agents, representing relevant decision institutions, like governments. Initially again, the majority of agents adhere to a perspective at the opposite end of natures actual dynamics, but there are small initial percentages of the correct and the intermediate (hierarchist) world views. In comparison with fig. 1 we see that the initially resembling time paths seem to 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.

However, what is interesting apart from this observable learning effect, are the problems, arising from such initial misperceptions and the time it takes to correct them. In a way the proposed scenarios underlying fig. 2 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. 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. Fig. 3 illustrates the shifting percentages of institutional perspectives for initially to many individualists (left) and too many egalitarians (right).

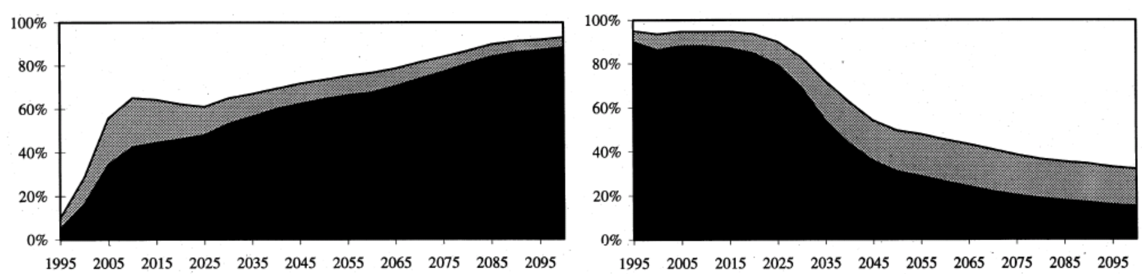

Fig. 3 Change of perspectives for adaptive agents. Left: initially high percentage of individualists in a vulnerable environment. Right: initially high percentage of egalitarians in a robust environment. ■ = egalitarians, ▩ = hierarchists and □ = individualists. Source: Jansson 1996: 59

Initially too low investments or too high emissions impinge on future development chances for decades to come. Temperature increase e.g. for the initially too market oriented world rulership reaches around 2.5° versus less than 1° if the correct policy is installed from the beginning on. Economic output, on the other hand, could have been 1/3rd higher by 2100 if the robust environment had been ruled by individualists form the beginning on (the comparisons were made with Fig. 3 in Jansson 1996: 55).

4 Why we need such models

The main contribution of agents-based climate-economy models, like the one sketched above, is the creation of 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 temperatures and economic damages. This is not saying that the corresponding scenario, with a very sensitive environment, is the most probable 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 three one after the other. 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. What is more questionable is the quite simplistic way in which actions are taken in the model. The agents only have 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. Finally, 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. Saying 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).

Finally, the model should be fed with newer data. The model and its data is more than 10 years old. Climate-economic dynamics deviate in several respects from the original model. 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 viewpoint. 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). The model as well as the agents' perspectives should be updated with current knowledge. Whereas climate-economic dynamics deviate in several respects from the original model, the agents' perspectives, as has been said, are still quite valid and only have to be altered, where new data suggest an update of information within the given beliefs. 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 and only might be emphasized a little.

5 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 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, but 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 putting more effort into such models. As a first step, the original Janssen (1996) model should be updated with current data, to investigate how much the outcome changes. It should then be tried to develop more empirically based representations of the agents' perceptions. Such a modelling approach is important to demonstrate the implications of different perceptions for climate policy and its consequences.

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