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Misperceptions of Global Climate Change: Information Policies

by

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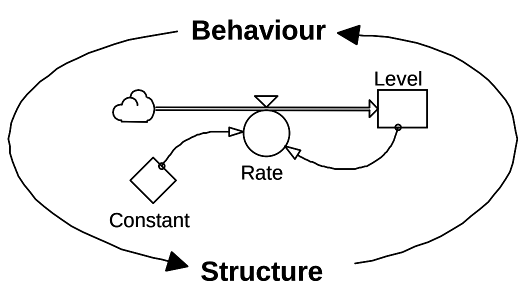

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ABSTRACT

Global climate change is an atmospheric commons problem where the basic actors are the states. In democratic nations national policy initiatives depend on the opinion of the electorate. Unless there is a proper popular perception of climate change, it will be difficult to undertake appropriate and timely measures. Previous experimental studies of people's understanding of climate change and of other renewable resource problems have revealed that people misperceive the basic dynamics and that they favour decisions that are systematically biased in the direction of over-utilisation. In the present laboratory experiment, with 251 students, the focus is on understanding why people misperceive and how misperceptions could be avoided. Using a simulator, the subjects are asked to control total global emissions of CO_2 to reach a given target for the atmospheric CO_2-concentration. Compared to a previous study we find that full information about a simplified system leads to improved performance, particularly among students with a background in mathematics. Subjects perform better in an analogous, however more easily visualisable system, indicating that they have difficulties forming appropriate mental models of the more abstract atmospheric problem. Two information treatments, thought to improve mental models, turn out to have insignificant effects. Finally, information feedback about the development of the CO_2-concentration helps. According to our findings, current information from the IPCC and the standard media coverage is not effective in helping people to choose policies that are consistent with their own preferences.

Keywords: Global climate change, laboratory experiments, dynamic decision making, misperceptions, information policies.

1. INTRODUCTION

Unlike many familiar tasks, the global climate cannot be properly controlled by trial-and-error strategies relying on outcome feedback about recent changes in the climate. Long delays between changes in policies, emissions of greenhouse gases (GHGs), changes in the atmospheric concentration of GHGs, and finally changes in temperatures and climate, imply that trial-and-error strategies will lead to overshooting behaviour. Therefore policies must be based on formal models. Knowledge about the key relationships in these models is also likely to be important for the formation of proper mental models among lay people, who in democratic nations have much to say over public policies to control emissions. Without a minimum of understanding of these relationships, lay people are invited to accept radical statements about the need to cut world emissions of for instance CO_2 by around 70 percent[1] just to stabilise the level of CO_2 over the next hundred years. Some people will dismiss such information because it is radical and impossible to understand; others may be able to repeat the numbers while voting behaviour is based on simplified and biased own mental models and heuristics. It is the purpose of this paper to contribute to a better understanding of the mental models people employ in these matters. We also address the question of information policies to improve mental models and decisions.

Previous research on dynamic decision-making shows that people have great difficulties in managing complex dynamic systems (Brehmer 1989; Sterman 1989;

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1 In IPCC's 3rd Assessment Report (2001, p. 76), based on the two fast carbon cycle models Bern-CC and ISAM, alternative stable CO_2 concentration scenarios and their associated CO_2 emission trajectories are illustrated. A careful investigation of these graphs reveal that for any reasonable

Brehmer 1992; Paich and Sterman 1993; Diehl and Sterman 1995; Sweeney and Sterman 2000; Kainz and Ossimitz 2002; Ossimitz 2002). Of particular interest are experiments with renewable resources showing strong tendencies towards overinvestment and overutilisation (Moxnes, 1998a, 1998b, 2000, and 2004). Moxnes argues that the main reason for overutilisation is that subjects tend to use static (correlational) mental models instead of proper dynamic models distinguishing the resource stock (state) and the flows that cause it to change (derivatives). Moxnes (1998b) postulates that the same misperception is likely and particularly important when dealing with global climate change. In an experimental study, Sterman and Sweeney (2002) in fact show that people misperceive the dynamics of the CO_2-concentrations in the atmosphere. Sterman and Sweeney find that people tend to use a “pattern matching heuristic” implying that if the task is to increase the CO_2-concentration, emissions should increase as well. If the task is to reduce the concentration, emissions should be reduced. The response in the first case seems unaffected by existing information about the need for radical reductions in CO_2-emissions just to stabilise concentrations. Both cases are consistent with a static (correlational) mental model.

Surveys show that people are concerned about the problem of climate change. For instance, a recent poll in the USA shows that the majority (almost three fourths) of the US public embraces the idea that global warming is a real and serious problem and rejects the argument that taking action is too economically onerous. However, the majority divides on whether the problem is pressing and should include steps with significant costs or whether the problem can be dealt with more gradually through low-

stable CO2 concentration that can be achieved within the next 100 years, CO2 emissions have to be reduced to about one third or one fourth of its current value within the next century.

cost steps (PIPA 2000). The latter view is consistent with the misperception we investigate here, and for the moment this view seems to be the dominant one in many or most countries. Hence it seems that current information policies have not been efficient in helping people choose policies that are consistent with their own preferences.

We want to contribute to a deeper understanding of the misperceptions of the basic stock and flow dynamics underlying climate change. Like the earlier studies, we make use of laboratory experiments. Our base case differs from the design used by Sterman and Sweeney (2002) in several ways. Most important, we use a highly simplified simulator of the CO_2-concentration in the atmosphere, we provide the participants with full information about the simulator, and they get an economic incentive to perform the best they can. In spite of this, the average performance is not much better than that observed by Sterman and Sweeney. Variations of the base case are made in four between-subject treatments. First, to test the ability of the participants to form proper mental models of the CO_2-simulator, we test their ability to manage a perfect mathematical analogy, presented as a leaky balloon. For this concrete and visualisable problem, performance is significantly better. Next, we test two information policies meant to help build appropriate mental models of the CO_2-problem. Unfortunately, they are not very effective. Finally, we use a feedback design, which gives significant improvement, however raises interesting questions about implementation of information policies. According to our results, current information policies by IPCC, governments and media are deficient and need improvement.

First we give some background information about the climate change problem. Then we present the model that we use in the simulator. After that we present the hypotheses and experimental design, the results, a discussion and the conclusions.

2. BACKGROUND ON CLIMATE CHANGE

The earth's climate functions as a heat engine driven by the sun. The earth continually receives heat from the sun in the form of short wave solar radiation and looses heat to the space in the form of long wave black radiation. The amount of long wave radiation is proportional to the world's absolute temperature. As the temperature increases, more heat is radiated back to the space. The world's temperature depends on the balance between the incoming and outgoing radiations. When these two are equal, the average temperature stays constant, when incoming radiation exceeds outgoing radiation the temperature increases.

The balance between in- and out-radiation is influenced by greenhouse gases (GHGs). As the concentration of these gases increases, out-radiation is reduced. As a result, the world's average temperature increases until the outgoing long wave radiation again balances the incoming solar radiation. Thus, the world's temperature level depends on the concentration of GHGs in the atmosphere. For instance, without the existing greenhouse blanket, the world's average temperature would be 31 ^{o}C lower than its pre-industrial average of 15 ^{o}C. (Ruddiman, 2001, pp. 18-21).

That is why the scientific community is seriously concerned about the world's climate in the near future. Water vapour (H_2O), carbon dioxide (CO_2) and methane (CH_4) are the major greenhouse gases existing in the world's atmosphere. The concentrations of these gases have been building up in the earth's atmosphere over the last 100 years at an increasing rate because of human activities. The annual anthropogenic carbon emissions mostly due to fossil fuel burning has increased from pre-industrial values of 50 million metric tons in 1850s to 6457 in year 1999 (Marland, Boden et al., 2002). The atmospheric concentration of the prominent greenhouse gas CO_2, has increased from its pre-industrial concentration of about 290 ppmv in the late 1800s to 369 ppmv by year 2000 (Etheridge, Steele et al., 1998; Keeling and Whorf, 2002).

The Intergovernmental Panel on Climate Change (IPCC)[2] has been emphasizing this fact since its first assessment report in 1990. Continued future growth in greenhouse gas emissions has been predicted to lead to significant increases in the average surface temperature of the planet. Now, based on the ten years of climate research in the interim, the most recent assessment report of the IPCC pronounces that concentrations of atmospheric greenhouse gases and their radiative forcing (long wave radiation trapping) have continued to increase as a result of human activities. The present CO_2-concentration has not been exceeded during the past 420,000 years and likely not during the past 20 million years (IPCC, 2001, p. 7).[3]

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[2] The Intergovernmental Panel on Climate Change was established by the World Meteorological Organisation (WMO) and the United Nations Environmental Programme (UNEP) in 1988. Its aim is to provide an assessment of the understanding of all aspects of climate change, including how human activities can cause such changes and can be impacted by them. IPCC reports are written and reviewed by over 1000 experts from all over the developed and underdeveloped world nominated by governments and international organizations.

[3] According to the IPCC there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities (IPCC 2001, p. 10). The global surface temperature of our world has increased since 1861. Over the 20th century, the increase has been $0.6 \pm 0.2\ ^{o}C$; it is very likely that 1990s was the warmest decade and 1998 was the warmest year in the instrumental record; the increase in temperature in the 20th century is likely to have been the largest of any century during the past 1000 years. Moreover, the overall global temperature increase triggered decrease in snow and ice cover. The frequency of heavy precipitation events, the cloud cover and the frequency and intensity of droughts were also observed to increase and these are attributable to human induced climate change (IPCC 2001, p. 4). Moreover, Greenhouse warming and other human alterations of the earth system may increase the possibility of large, abrupt, and unwelcome regional or global climatic events (USA National Research Council, 2001).

Though there is uncertainty about the costs and dimensions of human induced climate change in the near future, the contemporary dispute concerns policy responses to control GHG emissions rather than the predictions. The global atmosphere represents a case for a “common resource” problem, for which the states are the main actors, the stakes are extremely high and regulation is urgent but difficult. In this “common resource” problem, national GHG emissions create benefits for the emitters in the short term but the increased GHG concentrations create costs for the whole humanity in the near future. Although benefits are immediate for the emitters, the costs are not equally distributed among the rich and the poor, and between the generations. So far, FCCC and the Kyoto Protocol[4] to this convention represent the first step towards global cooperation for a climate treaty among world nations. Under the Kyoto Protocol, industrial nations have approved commitments to reduce GHG emissions to at least 5% percent below their 1990 emission levels between the years 2008 and 2012. But, the future of Kyoto and its beyond is not clear.[5]

The “commons” nature of the climate problem underlines most of the dispute and difficulties for an appropriate policy response. But, beyond this “commons” problem, it is not clear if the world community perceives the need for an immediate action. Today, for all practical purposes, world carbon emissions exceed the current removal rate of

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[4] United Nations Framework Convention on Climate Change: This convention was entered into force by 1994 and has received 166 signatures so far. The ultimate aim of the convention and its related legal instruments is to achieve stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic inference with the climate system. Parties to this convention agree on a broad international cooperation to develop and implement policies limiting national GHG emissions. The Kyoto Protocol was issued in year 1997 as a part of FCCC.

[5] First, the United State’s early ratification of the Protocol condition on “meaningful participation” and the arbitrary “Clear Sky Initiative” of the US government in year 2002 can effectively block cooperation among the industrialized nations. Second, the developing countries cannot reasonably be expected to restrict their future emissions without being assured of a fair allocation scheme that will not impair their ability to develop (Baer, P., J. Harte, et al., 2000). Without an equitable allocation of emission rights, current growth in developing countries such as China, India, Indonesia or Brazil are likely to exceed any limits to global emissions beyond reasonable measures within a few decades.

CO_2 from the atmosphere approximately by an order of two. This fact calls for a dramatic action if humanity is to stop human induced climate change. If the concentration of CO_2 is to be maintained approximately at its current level, world carbon emissions have to be reduced to about half of its current values. The later this action is taken, the larger and more severe the required emission reductions will be. But the public and popular climate discourse hardly speaks this truism. Even the IPCC reports are not outspoken about this fact and hard to interpret about the dimensions of carbon emissions compared to current absorption estimates.

3. THE MODEL

Although the world's climate is a complex system, the basics of global climate change can be captured by a simple dynamic model. The driving factor in climate change is the GHG concentrations. Among the GHGs, CO_2 plays the major role in heat trapping. To simplify we concentrate on this component. Figure 1 illustrates the simple CO_2-dynamics. The CO_2-concentration (the stock is depicted by a rectangular box) increases by carbon emissions (flows are depicted by pipes with a valve) and decreases by absorption of terrestrial and ocean ecosystems. As long as the carbon emissions (inflow) exceed absorption rates (outflow), the CO_2-concentration continues to increase. Only when the absorption rates equal the emissions, the CO_2-concentration will be stabilized, enabling a stabilization of the climate in the long term. The arrow from the CO_2-concentration to the absorption rate illustrates that the outflow depends on the concentration.

The process shown in Figure 1 is structurally analogous to for example the filling and the draining of a bathtub. With a similar representation, the stock variable can represent the water level in the bathtub while the inflow and outflow variables represent water flowing in and out.

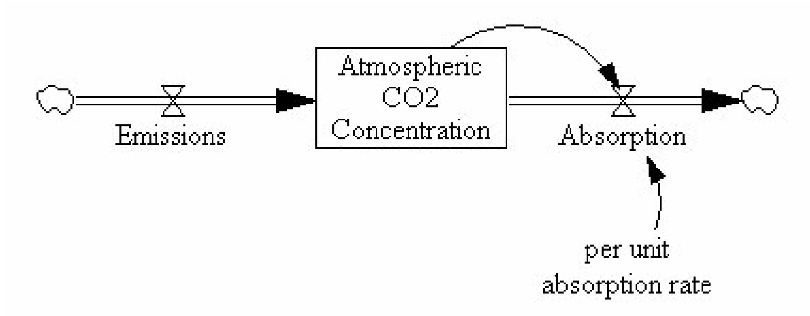

FIGURE 1. Atmospheric CO2-dynamics represented with a stock-flow diagram.

In the laboratory experiment the ideal choice of a simulator is one that is simple yet realistic. First we present such a model, and next we show that this model can explain quite well the last hundred years' development of CO_2-concentrations as well as a high and low IPCC scenario for the period 2000 to 2100. Equation 1 shows the mathematical formulation of the simple "bathtub" model:

(1) $$\frac{dC}{dt} = E - aC$$

In this equation, *C* represents the amount of CO_2 in the atmosphere above the pre-industrial level (296 ppmv before year 1900). *E* stands for the anthropogenic carbon emissions and *a* is the per unit absorption rate of (anthropogenic) atmospheric CO_2. The unit for *C* is billion tons carbon in the entire atmosphere and the flows are measured in billion tons carbon per year. The model is calibrated with respect to emission and concentration data for the period 1900-2000[6]. We estimate *a* to be 0.0233

[6] Etheridge, Steele et al. (1998); Keeling and Whorf (2002); Marland, Boden et al., (2002). The CO_2-concentration data in ppmv are converted to billion tons carbon in the entire atmosphere by a conversion factor of 2.13 billion tons/ppmv (Oak Ridge National Laboratory, 1990).

per year (implying a lifetime of approximately 43 years in the atmosphere). The upper graph in Figure 2 shows a close fit between the simulated and observed CO_2-concentrations. The lower graph shows the historical emissions and the carbon absorption rate as it is simulated by the model. By year 2000, emissions are about twice the size of the absorption.

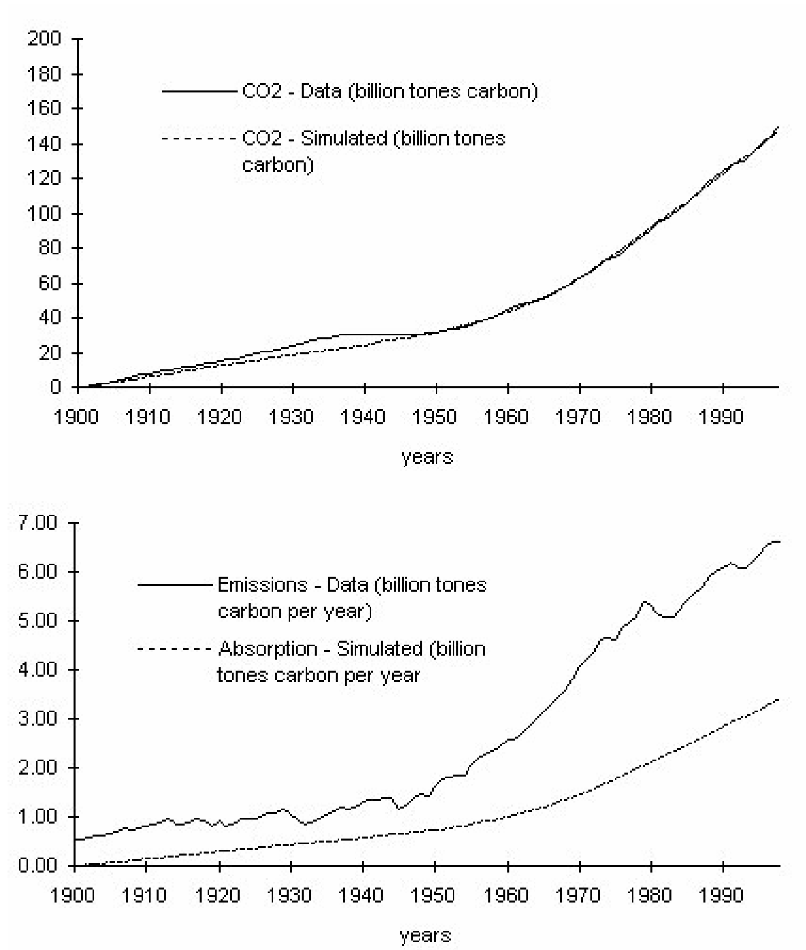

FIGURE 2. Model calibration with respect to historical data (absorption rate 0.023 per year)

Then we calibrate the per unit absorption rate *a*, to replicate both a high and a low IPCC scenario, SRES B1 and IS92a[7] for the period 2000-2100. A value of *a*=0.013 per

[7] In year 1992, IPCC published six alternative scenarios (IS92), which embodied a wide array of assumptions affecting the world's GHG emissions. Then in year 1996, they began the development of a new set of emissions scenarios to update the IS92 scenarios. The approved set of new scenarios is reported in the Special Report on Emission Scenarios (SRES). B1 is one of the marker scenarios

year (a lifetime of CO_2 in the atmosphere of 77 years) gives an acceptable fit for both scenarios, see Figure 3. The low value of *a* summarizes the assumptions of large scale climate models regarding future carbon absorption rates. The absorption capacity of carbon reservoirs decreases over time. Consistent with this, a simple nonlinear relationship between the CO_2-concentration and the absorption rate would lead to an even better fit between our model and the IPCC scenarios. Using such a model we would not need to operate with two distinct values for *a* before and after year 2000. However, since the fit is already more than good enough for our purpose, we simplify by using the linear model for the period 2000 to 2100.

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in SRES and IS92a is a member of the old scenario family. The emissions and corresponding CO_2-concentrations for this calibration are taken from the graphical illustrations as presented by IPCC (2001, p. 64).

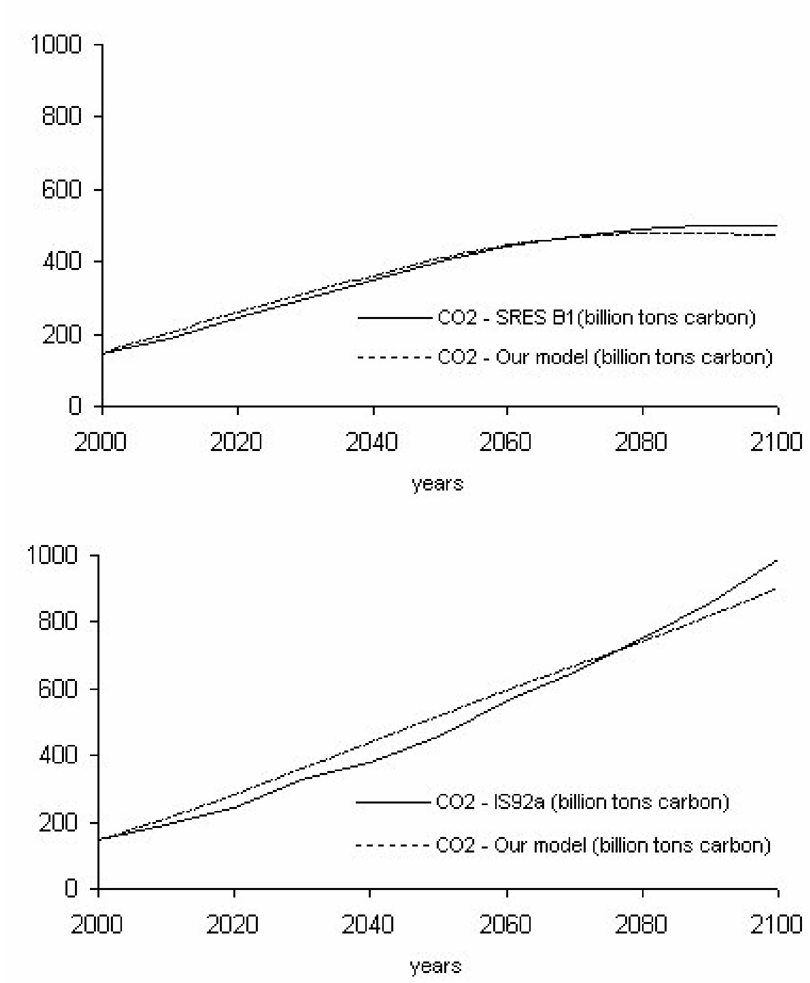

FIGURE 3. Model calibration with respect to IPCC scenarios B1 and IS92a (absorption rate 0.013 per year)

4. EXPERIMENTAL DESIGN

4.1. The task

Figure 4 shows the simulator interface. The goal for the participants is to stabilize the atmospheric CO2-concentration between the years 2040-2100 and the task is to determine one hundred years of carbon emissions between the years 2000-2100. The experiment starts in year 2000 where the global annual carbon emissions are set at 8 billion tons and the atmospheric CO_2-concentration over pre-industrial level is set at 150 billion tons carbon.[8] The target CO_2-concentration is set at 300 billion tons carbon (circa 437 ppmv) to be achieved in all years between 2040 and 2100.[9] The dot and the straight line in the concentration graph illustrates the starting point and the target.

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[8] In SRES scenarios of IPCC (IPCC, 2001), the carbon emissions are close to 8 billion tons per year in year 2000. 150 billion tons-carbon CO_2 over pre-industrial level stands for circa 366 ppmv, close to the 369 ppmv suggested by data (Keeling and Whorf, 2002).

[9] IPCC's best-case stabilization scenario sets target CO2 level very close to our choice, as 450 ppmv by year 2050 (IPCC, 2001). IPCC stabilization scenarios discuss various stable CO_2 paths and related paths for carbon emission reductions produced by two carbon cycle models Bern-CC and ISAM. Each path consists of upper and lower boundaries to reflect uncertainty. According to the 450 ppmv stabilization scenario, a moderate assumption on climate sensitivity implies temperature increase of approximately 2 ^{o}C by the end of 21st century. To put this number in perspective, the observed warming in the 20th century was 0.6 ± 0.2 ^{o}C and during the last glacial period 21000 years ago, the Earth's temperature was only 4-8 ^{o}C cooler than today. According to the carbon cycle models, this best-case scenario calls for a gradual decrease of emissions to 25% of today's emissions by the year 2100.

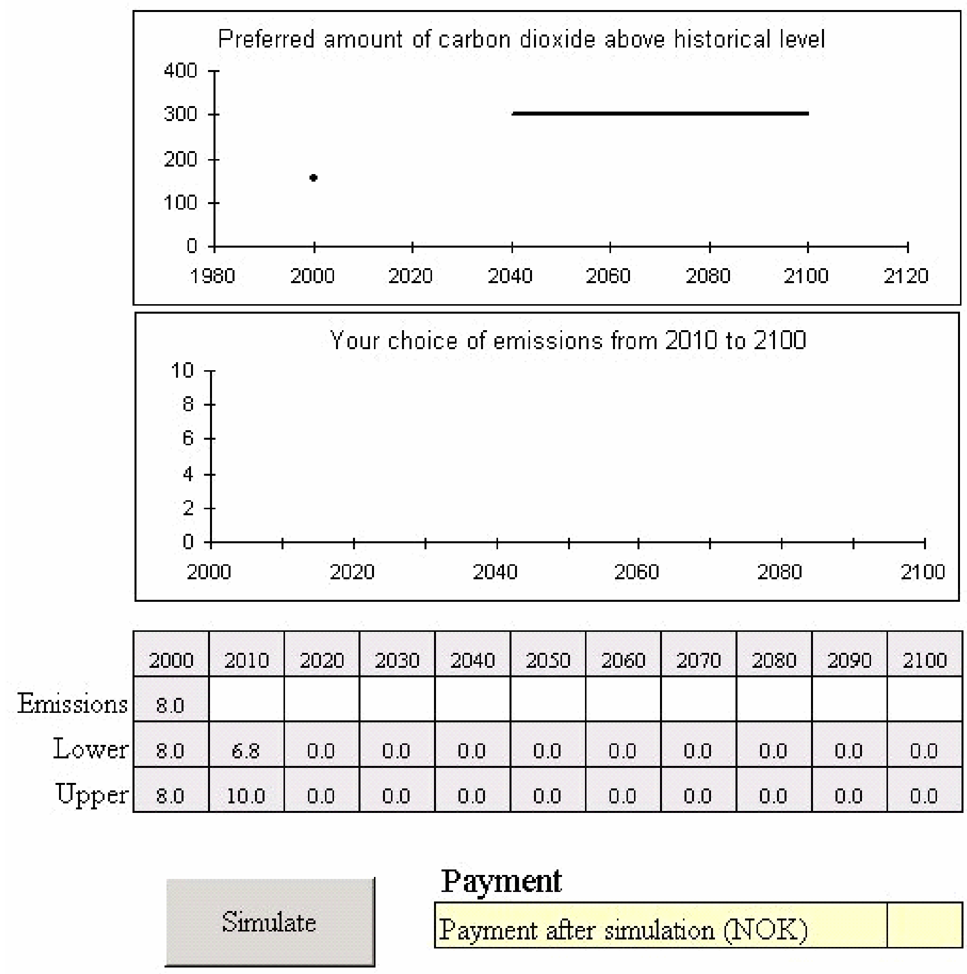

FIGURE 4. Simulator interface.

The atmospheric commons problem is ruled out by the design since each subject has full command on the total, global carbon emissions. They do not compete with any rivals to increase their individual short-term benefits, and they do not have to cooperate with anyone else to increase common long-term benefits.

To avoid unrealistic changes in emissions, the rate of change in carbon emissions over each ten years period is restricted to +25% and -15%. Any reduction below 15% in a ten year time period is likely to underestimate world economic growth, increasing energy requirements and the costs and time needed to increase energy efficiency. The 25% upper limit allows for increases due to world economic growth and movements towards a more fossil fuel intensive economy. Within these limits, subjects enter their emission choices for every ten years in the table under the graphs. Emissions outside the boundaries lead to error messages. As the subjects enter their figures, they see the resulting emission trajectory in the graph. If people are not normally conscious about these limitations on changes in emissions, our instructions may affect the results of the experiment in the direction of earlier and stronger curtailments.

When the entire emission trajectory is decided for 2000-2100, subjects hit the simulate button and see the resulting CO_2-concentration and how much they earned. The payments are in proportion to their success in achieving the target. The closer they are to the target concentration between 2040-2100, the more they earn. The design allows the subjects go below the target concentration level as well as above.

The instructions provide the subjects with a context and with full information about the structure and parameter values of the underlying simulation model. During the experiments, subjects were allowed to use calculators and they had ample time to work on the problem. Privacy of the results was announced in the instructions and the participants were placed in cubicles. Appendix A provides the full instructions for the base experiment.

Given that the subjects form appropriate mental models of the problem, only elementary math skills are needed to identify an appropriate emission trajectory. Here we illustrate how a benchmark can be established by simple means. The subjects know that the task is to stabilize the CO_2-concentration at 300 billion tons and that the per unit absorption rate is 0.013 per year. The concentration is stabilized at this level only if the emission rate equals the absorption rate. When the concentration is 300 billion tons, the absorption rate must be 300x0.013=3.9 billion tons per year. Therefore, when stabilized, the emissions must also equal 3.9 billion tons per year. Thus a first rough benchmark policy is to gradually reduce the emissions from the initial rate of 8.0 billion tons per year to 3.9 by 2040. This policy is guaranteed to lead to the desired concentration of 300 billion tons in the very long run.

However, to safeguard that the concentration ends up close to 300 billion tons already in 2040, one may fine tune by considering the net rate of change in the concentration from 2000 to 2040. If for instance the emission rate is kept at 8 billion tons per year for the first ten years, and the absorption rate stays around 2 billion tons per year (ignoring that it increases somewhat with the concentration), the increase in the concentration is 60 billion tons. Over the next thirty years (from 2010 to 2040) the emission rate is reduced linearly down to 3.9 billion tons per year, while we assume that the absorption rate linearly increases to the same level. The area of the triangle denotes the net rate of change in the CO_2 concentration and equals 90 billion tons. Altogether the two periods add around 150 billion tons to the initial level of 150 billion tons. Thus the goal of 300 billion tons should be reached close to 2040. Assuming that the emission rate is reduced linearly from the very beginning, and that the absorption rate increases linearly, gives a triangle with area of 120 billion tons. This is not quite sufficient to reach the goal. Figure 5 illustrates the results of a simulation where the reduction in emissions is delayed by 10 years. This strategy serves as our benchmark since it represents an upper path for emissions.

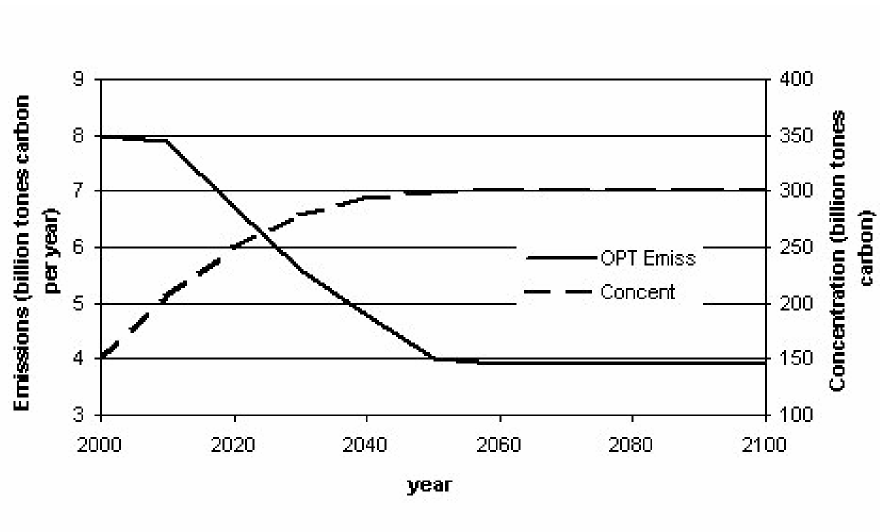

FIGURE 5. The benchmark and corresponding CO_2-concentration.

4.2. Subject Groups

Three subject groups participated in the experiments. The first subject group, from Bogazici University – Istanbul, Turkey (IST), consisted of 97 graduate students from engineering, economics and natural science departments who study mathematics and calculus courses before and during their graduate education. The second group, from Bergen University, Norway (MN), consisted of 75 graduate students from the Faculty of Mathematics and Natural Sciences. They all study mathematics and calculus. The third group was 79 graduate students from Bergen University, Faculty of Arts (HF), who do not study mathematics and calculus and thus have a limited knowledge of these topics.

After the experiments, the subjects filled in a questionnaire, regarding their age, gender, level of education, environmental knowledge and concerns about environmental problems. The questionnaire also contained questions to test the subjects' level of understanding of the simulator and to get their response to the observed model behaviour. The questionnaire is provided in Appendix B.

Table 1 shows the results that help characterise the subject groups. The IST group is younger and dominated by male students when compared to MN and HF. Environmental knowledge of IST is poorer than that of MN and HF. Environmental concern in IST is slightly less than that of HF. Concern in IST about global CO_2-emissions is less than that of MN and HF. Finally, the ability to calculate the absorption rate at the desired amount of CO_2, 3.9 billion tons per year in question 13, identifies those who are able to calculate the desired absorption rate when asked specifically. This ability is higher for MN than for the two other groups.

TABLE 1. Subject groups and significant differences

Subject Characteristics	IST	MN	HF
1. Average age	20.5	22.6	21.9
2. Gender - male (%)	80	61	47
3. Average environmental knowledge (questions 5.1 to 5.5) 0: all wrong; 1: all correct	0.43	0.58	0.54
4. Average environmental concern (questions 6.1 to 6.6) 0: minimum concern; 1: maximum concern	0.70	0.72	0.74
5. Average concern about CO_2-emissions (question 6.1) 0: minimum concern; 1: maximum concern	0.69	0.85	0.90
6. Ability to calculate absorption rate (questions 13), %	26	44	24
Significant differences: 1. Age of IST is different from that of MN and HF (p=0.004 and p<0.0001, M-W tests). 2. The proportion of males in IST is different than in MN and HF (p=0.007 and p<0.001). 3. Environmental knowledge in IST is different from that of MN and HF (p<0.0001 and p=0.0004, M-W test). 4. Environmental concern in IST is different from that of HF (p=0.035, M-W tests) 5. CO_2-emissions concern in IST is different from that of MN and HF (p<0.0001 and p<0.0001, M-W tests). 6. The proportion of successful absorption rate calculations for MN is different from that of IST and HF (p=0.014 and p=0.008).			

4.3. Treatments

The CO2 stabilization task in the base treatment (T0) can be compared to a similar task in Sterman and Sweeney (2002). In both experiments, the task is to select carbon emission trajectories over the next century that stabilize the CO_2-concentration at a level higher than today. Sterman and Sweeney observed a strong upward bias in emissions. Our reference experiment (T0) deviates from their design in three major ways. First, their presentation of the task draws on the presentations in IPCC documents, and the information about the system is not complete such that the subjects are faced with ambiguity. We present a simplified problem with full information. Second, we motivate the subjects by monetary incentives. Third, we mention explicitly that there are upper and lower limits for changes in emissions over future ten year periods. Sterman and Sweeney avoid unrealistic behaviour by having the subjects choose between a limited number of emission paths. We hypothesise that our design will lead to smaller biases, particularly for those with comparable skills to the subjects in Sterman and Sweeney's study.

To solve the task, the participants must formulate their own mental models, in which the given data can be utilised. The complexity of this undertaking should not be underestimated, particularly for those who have no training in formulating dynamic models. A previous study by Brigham and Laios (1975) suggests that direct inspection of a physical system helps the construction of mental models. Here we hypothesise that if the instructions describe a system that is easily visualisable rather than diffuse, it will also help the construction of appropriate mental models.

To test this hypothesis we use a treatment (T1) which is mathematically and numerically identical to T0. However, T1 is presented as a physical problem that can be easily visualised by the subjects. The task is to inflate a leaky balloon and to stabilize the amount of air in the balloon within the next 40 to 100 minutes. To make the task sound practical, the subjects are told that after the next 40 minutes children will be jumping and playing on the balloon. Therefore its air pressure has to be stabilized at a desired level so that the children do not get hurt. The instructions for this treatment are given in Appendix C. We hypothesize that the treatment reduces the bias. If so, this is an indication that subjects have problems formulating proper mental models of the less visualisable CO_2 problem.

If people perform better with the balloon framing than with the CO_2-framing, the balloon analogy could be used in information campaigns. The second treatment (T2) is designed to test this idea. In addition to the information given in the reference treatment (T0), the subjects are provided with a supplementary diagram where CO_2 in the atmosphere is illustrated by a gas balloon with two openings. Through the first opening, the emissions enter. The second opening is an outlet for CO_2 representing the absorption of carbon by plants and oceans. Then it is explicitly stated that only if the absorption exceeds the emissions, the amount of CO_2 in the balloon can decrease. These additional instructions are shown in Appendix D. For this treatment to have an effect, people must be better able to deal with the balloon analogy than with the CO_2-problem (tested in treatment T1), and they must be willing to use the balloon analogy to structure their mental model of the CO_2-problem. The latter undertaking requires that the analogy is accepted as valid (compatible with the subjects' mental models) and that the analogy is not perceived as redundant information (requires that the subject are motivated to improve current mental models and that they are not overly confident in their present mental models). Hence, we expect a smaller effect of treatment T2 than of T1.

Rather than building on an analogy, an information campaign could also try to highlight the key aspects of the original CO_2-problem. From previous studies it is known that people have problems dealing properly with, and distinguishing, stocks and flows. If people assume that the salient flow and the connected stock are linked by a direct, algebraic and static relationship, as suggested in Moxnes (1998b), it is natural to apply a pattern matching heuristics as found in Sterman and Sweeney (2002). In the CO_2-problem it is likely that the outflow, the absorption rate receives little attention and is ignored for that reason. While we have seen graphs depicting historical developments of fossil fuel burning and of estimated CO_2-emissions, we have not seen similar graphs of CO_2-absorptions. Rather, we have read about the current lack of knowledge about what the important sinks are. Thus, direct measurements of the absorption rate are not easily available, and this may explain the apparent lack of information about the absorption rate. On the other hand, our simulation model produces an estimate of the historical absorption rate which is consistent with the measures we have of the emission rate and of the CO_2-concentration in the atmosphere (Figure 2). This is the type of information we utilise in the third treatment, T3.

In T3 a graph shows the relationship between the absorption rate and the CO_2-concentration in the atmosphere, see Appendix E. In the same figure historical emissions are shown as a function of the concentration. The figure makes clear that the current emissions are considerably higher than the absorption rate. The attached text explicitly states that as long as the emissions are larger than the absorptions, the amount of CO_2 in the atmosphere will increase. The graph can be easily used to see where the future equilibrium point is and to see that emissions must be reduced. A quite similar treatment in Moxnes (1998) gave significant effects. However, as in that case, we expect that a limited ability to read such a graph correctly, will imply that the full potential is not reached. In particular we expect a limited ability to distinguish stocks and flows to reduce the effect of the treatment.

Whenever systems are complex, ambiguous or influenced by unpredictable events, decision makers must rely on outcome feedback. Outcome feedback enables people to apply trial-and-error strategies and to correct for unexpected events. Reliance on outcome feedback is a very natural process, and is long ago hypothesised to be a key element of human decision making (Forrester 1961). For example, when filling a glass of water, we typically close down the valve when we see that the glass is about to get full. We do not calculate for how long the valve must be open and then use this estimate to close it. Hence, we hypothesise that feedback will be used and will help correct decisions over time in the CO_2-task. To test this, in the final treatment (T4) the subjects receive precise information on atmospheric CO_2-concentrations every ten years before they decide on carbon emissions for the next ten years. We hypothesise that this treatment will reduce the bias towards over-emissions. Since the system is a very simple one, we expect the results to be better than in a large number of previous laboratory experiments of more complex dynamic systems allowing for outcome feedback (see references in the introducdtion). On the other hand, it may be less realistic to allow for outcome feedback in this particular problem than in previous studies because of the very long time delays. It could be that every time the CO_2-problem is considered, information and expectations decades old may be forgotten. In the discussion section we will return to how the real life feedback effect can be strengthened.

Altogether 251 subjects participated in the experiment. To avoid learning effects, no subject participated more than once. Table 2 shows the number of participants distributed over subject groups and treatments.

TABLE 2. Experimental design.

	IST	MN	HF	Total
T0	25	16	18	59
T1	15	16	20	51
T2	20	15	17	52
T3	19	13	17	49
T4	18	15	7	40
Total subjects	97	75	79	251

5. RESULTS

Figure 6 summarises subject performance in the five treatments. The upper graph shows the average absolute discrepancy from the target CO_2-concentration over the period 2040-2100. This is the criterion used to determine success and payoffs for the subjects. On average the discrepancy for the reference case (T0) is greater than 150 billion tons, which is more than 50 percent of the target. The average discrepancies vary over the other treatments from less than 50 to nearly 250 million tons. The variation is smallest for the MN group.

Since our main interest is in the bias towards over-emissions and not in the average absolute discrepancy from the target, the lower panel shows average upward biases (actual CO_2-concentrations minus the target). Since the experimental design allows subjects to go below the target CO_2-concentration as well as above, the two graphs need not be identical. However, very few subjects end up below the target and the two figures turn out to be nearly identical.

The bias is large in the base treatment (T0) especially for the IST and HF groups. For all three groups it ranges from around 50 to around 230 billion tons. The physical analogy (T1) and feedback (T4) treatments work quite well for all subject groups with average biases ranging from around 15 to around 65. The effects of the information treatments based on the balloon information (T2) and the explicit absorption rate information (T3) are not promising. Average biases range from around 85 to around 240 billion tons. Comparing the student groups, the MN group seems to do better in the treatments where the IST and HF groups perform particularly poorly.

Error!

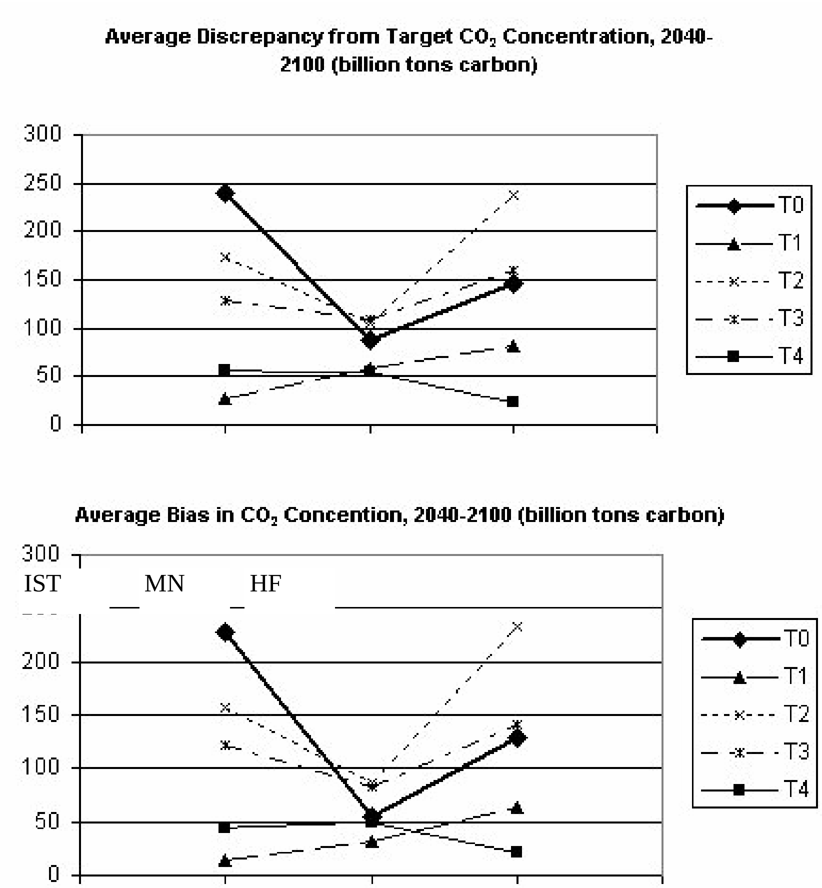

FIGURE 6. Summary of subject's performance under different treatments

5.1. Emissions and the benchmark

The graphs in Figure 7 show 95% confidence intervals for average emissions for each treatment and subject group. The overall impression is that only in a few instances the confidence intervals stretch below the benchmark path for emissions. Thus, the main impression is that of a widespread tendency towards over-emissions.

Considering T0 there is a clear upward bias for the IST and HF groups, the MN group is more of a borderline significant case. Roughly, the upper emission bounds for all three groups increase while the CO_2-concentration is supposed to increase until 2040. This finding is consistent with the “pattern matching” heuristic suggested by Sterman and Sweeney (2002). The subjects that contribute to this development are highly likely to have misrepresented the stock and flow relationship between the concentration and the emission/absorption rates. Their policies are consistent with a static relationship between emissions and concentration (simple correlation). The lower bounds for MN and HF do not show this tendency, indicating that some subjects do not apply this heuristic.

For the physical analogy (T1) the emission biases are smaller than in T0.[10] Still, since individual variations are smaller, the biases are roughly borderline significant for all groups. All upper confidence limits decline after 2010. This suggests that most subjects employed a more correct mental model of stocks and flows than in T0. There is less evidence of a pattern matching heuristic.

Emission boundaries for the balloon information treatment T2 show that this treatment does not work well for any group. The bias towards over emissions and the evidence of pattern matching heuristics are in place and similar to T0. Similar results are obtained for the absorption rate treatment T3.

Finally, the feedback treatment (T4) appears to have much the same size effects as T1. Just after 2000 the behaviour is similar to T0. However, feedback about rapidly

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[10] To simplify we use the same time scale as for the other graphs, even though the experiment lasted for only 100 simulated minutes.

increasing CO_2-concentrations over the next couple of decades makes subjects depart from the strategies that would normally follow from isolated uses of improper mental models. Note however that reliance on feedback introduces delayed reactions. Only in the last few decades of the experiment are average emissions not significantly larger than the benchmark.

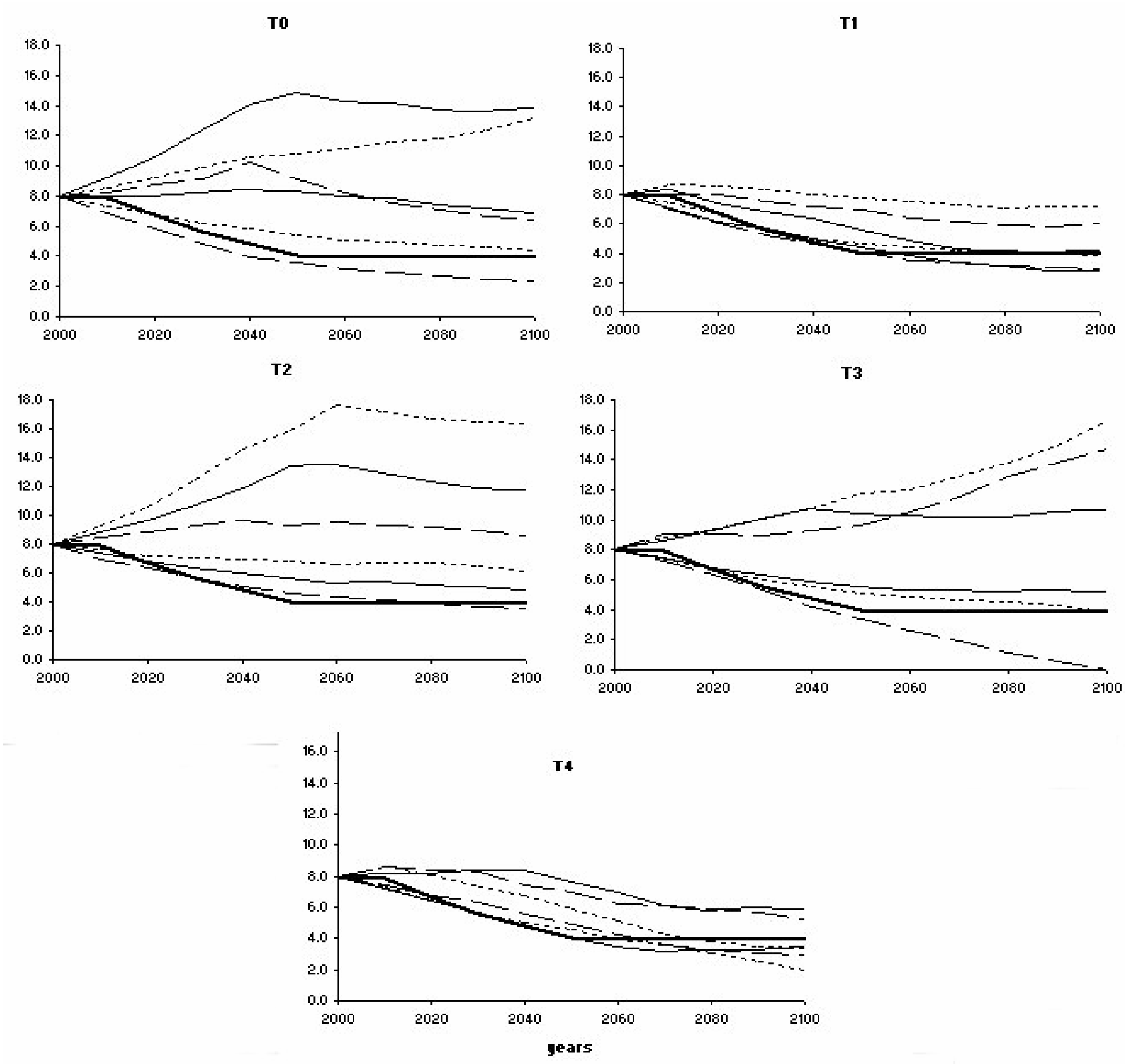

FIGURE 7. The benchmark emission path and 95 percent confidence intervals for emissions over treatments and groups.

Figure 8 shows confidence bounds for the average CO_2-concentration levels for the different groups and treatments. The tendency in the long term is towards

stabilisation in spite of higher than benchmark emissions. This may be overly optimistic compared to the real world since we have assumed the absorption rate to be proportional to the CO_2-concentration. If we had used a model with a saturating absorption rate, which may be more realistic, the concentration would not have stabilised in the long run.

Here we use these graphs to comment on differences between the three groups. In treatment T0 we see that the MN group performs borderline significantly better than the IST group, the HF group falls in between and is not significantly different from the two other groups. In the four other treatments there are no significant differences.

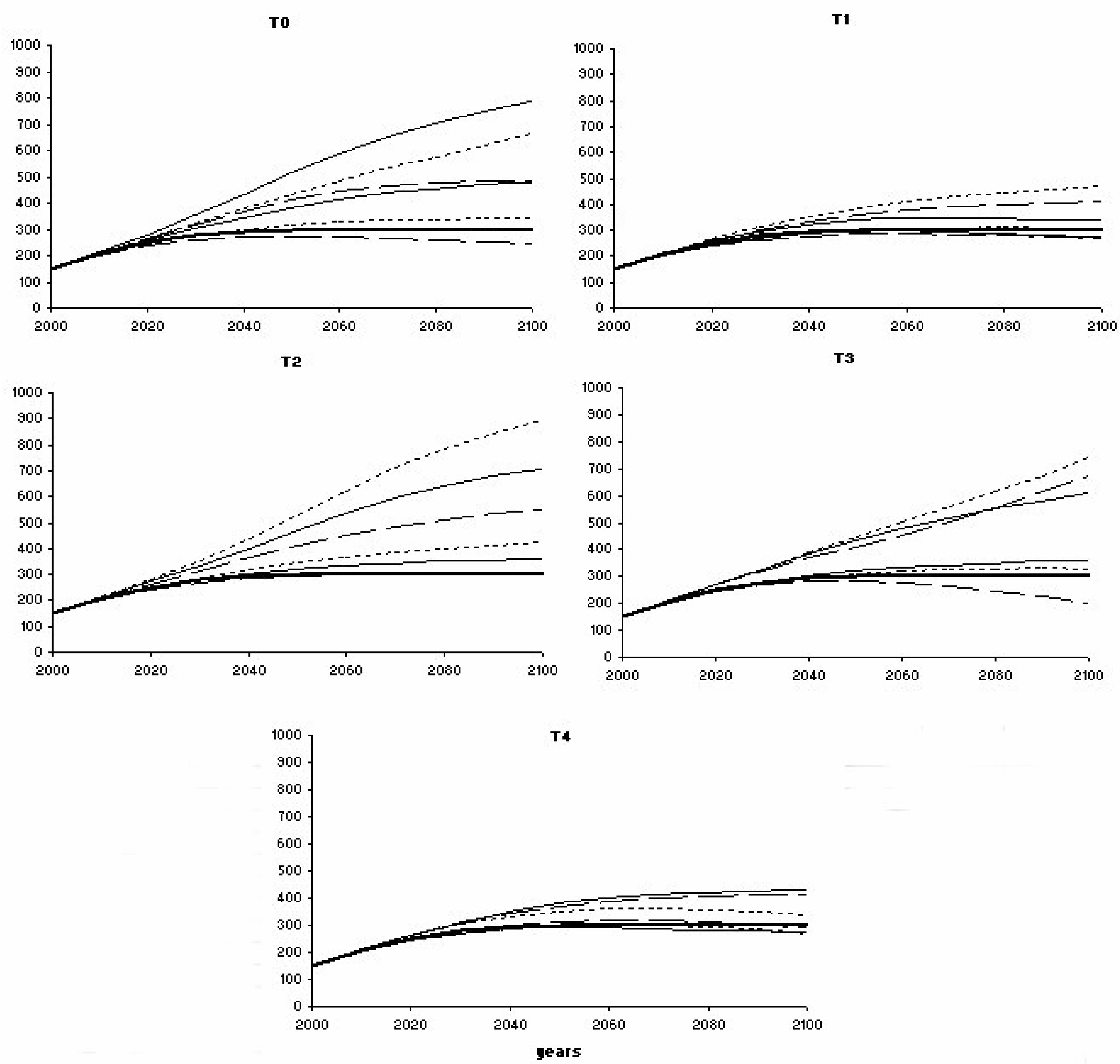

FIGURE 8. The benchmark concentration path and 95 percent confidence intervals for concentrations over treatments and groups.

5.2. Regression analysis

To get a better idea about the effects of treatments and subject backgrounds we perform a regression analysis. Since the groups have different backgrounds and are likely to benefit differently from the various treatments, we run separate regressions for the groups. In addition we split the groups according to their ability to calculate the equilibrium absorption rate (Question 13). This is a further attempt to split the groups according to analytical abilities.[11] Those who are able to calculate the equilibrium absorption rate, are classified as *Able* the others as *Unable*.[12]

A pilot regression analysis, not reported here, showed that the subject attributes age, gender and environmental knowledge did not have statistically significant effects on behaviour. Since we have no strong prior reasons to expect that these variables play a major role[13], and since their inclusion has negligible effects on the other parameters, we safely leave them out of the following regression. We do however include the subjects' responses to the question about their concern about the climate change problem (Question 6.1). Attitudes are generally thought to be important for decision making and are targeted in information campaigns.

Equation 2 shows the regression model.

$$y_i = \alpha_0 + \alpha_1 Concern_i + \sum_{k=1}^{4} \beta_k T_{ik} + \varepsilon_i \tag{2}$$

The response variable y_i is the average CO_2-concentration between 2040-2100 for each subject *i*. $Concern_i$ is the score obtained from the question about the concern towards current CO_2-emissions (Question 6.1; 1=highest concern, 0=lowest concern). T_{ik} represents treatment dummies for the different subjects *i, i*=1, 2, 3, and 4.

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[11] It is not of any concern that we do not know whether those who answered this post question correctly, performed the same calculation when dealing with the main task. The ability to perform the task when explicitly asked, is what is taken as a characteristic here. In a separate regression we found that the ability to answer the question correctly is not significantly influenced by any of the treatments in the two groups MN and HF. In the IST group, there is a significant improvement effect for T1, the physical analogy, but not for any of the other treatments. This may cause us to underestimate the effect of T1 for the IST group. However, this is of little concern since we do find a significant effect of T1 for the IST group anyway.

[12] Alternatively, the ability to answer the question about the equilibrium absorption rate could have been included as an explanatory variable using pooled data. In such a regression we found that the relationship between the ability to answer the absorption rate question correctly and the average CO_2-concentration obtained in the experiment to be highly significant. When the question was answered correctly as opposed to incorrectly, the average CO_2-concentration was lowered by 79 billion tons. The p-value for that coefficient was 0.001.

Table 3 shows all the regression results. The number of subjects is 242, nine less than the total number of subjects. The excluded nine participants did not fill in the questionnaires. Treatment 1, the physical analogy, has a significant effect for both *Able* and *Unable* in the IST group and for *Able* in the MN group. The subjects do better when dealing with the physical analogy. For the HF group the effect is in the same direction, however, it is not significant. Treatment T2, the balloon information, does not have a significant effect in any of the groups. It may be interesting that all three *Able* groups show stronger effects of T2 than the respective *Unable* groups.

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[13] At the outset one may suspect that environmental knowledge is important. However one must distinguish the factual knowledge that was asked about in the questionnaire and the structural understanding required to solve the problem, see e.g. Broadbent et al. (1986).

Table 3: Regression results by groups (IST, HF and MN) and by answer to the absorption rate question (Able and unable to answer correctly)

Predictor		Coefficient	t-ratio	p-value	N	R^2
IST	*Able*				25	0.41
Constant		762	5.4	0.000		
T1		-296	-3.1	0.006		
T2		-136	-1.3	0.23		
T3		-213	-1.5	0.16		
T4		-324	-2.2	0.040		
Concern		-230	-1.5	0.16		
	Unable				67	0.15
Constant		569	8.7	0.000		
T1		-195	-2.1	0.040		
T2		-65	-1.1	0.27		
T3		-91	-1.6	0.11		
T4		-165	-3.0	0.004		
Concern		-80	-1.0	0.30		
MN	*Able*				32	0.23
Constant		514	6.6	0.000		
T1		-98	-2.1	0.042		
T2		-69	-1.5	0.14		
T3		-75	-1.7	0.096		
T4		-74	-1.6	0.11		
Concern		-147	-1.8	0.085		
	Unable				40	0.31
Constant		667	5.2	0.000		
T1		25	0.4	0.66		
T2		103	1.6	0.11		
T3		99	1.4	0.18		
T4		44	0.7	0.48		
Concern		-366	-2.6	0.012		
HF	*Able*				18	0.06
Constant		309	1.6	0.13		
T1		-58	-0.7	0.47		
T2		-41	-0.5	0.65		
T3		-44	-0.6	0.58		
T4		-59	-0.5	0.66		
Concern		51	0.2	0.81		
	Unable				57	0.19
Constant		358	3.0	0.004		
T1		-70	-1.0	0.33		
T2		104	1.4	0.16		
T3		45	0.6	0.55		
T4		-137	-1.5	0.14		
Concern		117	1.0	0.32		

Treatment T3, the absorption rate information, does not show significant effects. There is a systematic difference between *Able* and *Unable* as for T2. Treatment T4, the feedback treatment, has a significant improvement effect for both *Able* and *Unable* in the IST groups. There are similar, however weaker and not significant effects in the *Able* MN group and in both HF groups. Except for the HF group, the favourable effect of T4 is greater for *Able* than for *Unable*.

Thus, with only one exception in the samples, subjects in the *Able* groups benefit more from treatments T2, T3 and T4 than those in the *Unable* groups. This suggests that the efficiency of information treatments depend on the analytical abilities of people. It also seems that the effect of attitude depends on analytical abilities. Only in the two groups for the MN group does the reported *Concern* about climate change have a significant effect on the results.

6. DISCUSSION

Consistent with the earlier studies, the present study shows a clear tendency towards biased decision making regarding CO_2-emissions. If politicians and voters believe that weak reductions in CO_2-emissions relative to the historical trend are sufficient to prevent climate change, efforts to curtail emissions will be weaker than needed to meet desired goals. This tendency is illustrated by our finding that although 86% of the subjects expressed that nations should make stronger reductions in GHG emissions, only 51% chose to actually reduce emissions in our experiment, and only a small minority reduced the emissions sufficiently to reach the stated goal. Concerns about climate change and proper attitudes do not by themselves help quantify the proper size of emission reductions. Thus, this problem calls for better and more effective information policies to be used by IPCC and all others trying to combat biased perceptions. In this regard our study gives important directions for the design of information policies and it will hopefully stimulate intensified further research in this area.

First, our base treatment differs from that of (Sterman and Sweeney 2002) with respect to complexity. In their experiment, the problem is presented in a naturalistic context, similar to the information given for example in IPCC reports. We present a fully adequate, however simplified version of the problem, with full information about relationships and parameters. In their case only 39 percent of the subjects chose to reduce emissions (still not sufficient to reach the benchmark) when they were challenged with the task of stabilizing CO_2-concentrations at a higher level than the current one (similar to our task). In our case pooled results show that 51 percent chose to reduce emissions (over the first 20 years to come close to the definition used by Sterman and Sweeney). In our subgroup with students in mathematics and natural science, the MN group, this percentage was as high as 81. These results suggest that a simplified problem description helps improve performance for groups that are able to deal with the mathematical/structural properties of the simplified description. While on a world scale, the group of people skilled in mathematics is only a tiny minority, it may be an important group to the extent that they serve as authorities or change agents (see the literature on diffusion of innovations, Rogers 1995).

While it may seem obvious that complexity should matter, the comparison between the experiments deserves further investigation since our base treatment also differs from the design used by Sterman and Sweeney in other regards than complexity. As already indicated the subject groups differ. Since many of the Harvard and MIT students used by Sterman and Sweeney were skilled in mathematics, differences in skills are not likely to explain the difference between the two studies. The experiments also differed with respect to incentives. While our students were paid according to performance, the Harvard and MIT students participated in experiments that were part of the class work in courses they had signed up for. While economic incentives are often found to have some positive effects on performance, it is not very likely that the economic incentives outperformed the course work incentives.

Second, the physical analogy treatment, T1, had a positive effect on performance in five out of six subgroups. The effect was statistically significant for both subgroups with mostly engineering students (the IST group) and for the *able* group with math skills (the *able* MN group). The physical analogy was identical in structure and parameters to the original CO_2-problem in the base treatment. Therefore the difference in performance must be related to the subjects' ability to form appropriate mental models or representations of the two problems, and not to the ability to control the system. The balloon analogy is familiar and presents itself as a stock and flow problem because of its physical appearance. The CO_2-concentration in different atmospheric layers around the world is a more abstract phenomenon that is less likely to present itself as a stock and flow problem. This explanation is consistent with the findings in Brigham and Laios (1975) where visual inspection and direct control of a hydrologic system lead to good performance while a description of the system together with state information given in remote meters lead to poor performance.

Even though the physical analogy leads to improved performance, the effect for the HF group is rather weak and statistically insignificant. This could be because also the balloon analogy was foreign to the HF students. The inability to form proper mental models from complete system descriptions suggests that there is a deficiency in the current educational system, particularly for those with little background in mathematics. Most students do not learn how to represent and deal with (abstract) dynamic problems. For a textbook that provide both an analytical and intuitive approach to dynamic systems see Sterman (2000).

Third, the balloon information treatment, T2, was meant to strengthen the impression of the CO_2-task as a stock and flow problem. In none of the subgroups the effect of this treatment was statistically significant, although the performance improved in all groups with *able* subjects. Why did not this information treatment work when the physical analogy worked when presented as such? The following explanation seems likely. Given that most subjects perceive the CO_2-problem as abstract and difficult, an analogy could easily be perceived to be imprecise and unreliable, even though it was a perfect representation in our case. If so, the analogy could contribute to information overflow just as well as clarification of the problem structure. The result parallels that of Moxnes (1998b), where a perfect bathtub analogy of a renewable resource problem had no effect on performance. In this connection it is also interesting to note the observations of limited transfer of knowledge between less than perfectly analogous problems (Bakken 1993) and (Jensen 2003). Again, more adequate education in dynamic systems could help students make use of analogies - after all, many apparently different systems share basic underlying structural properties.

Fourth, the absorption rate information treatment, T3, was meant to strengthen the impression that the initial emission rate was much higher than the initial absorption rate. The graph showed the absorption rate as a function of the CO_2-content of the atmosphere with the historical emission rates in the same graph. In four out of six subgroups the effect had the expected sign. However, only in the *able* MN group was the effect marginally significant at the 10 percent level. The weak effect is probably related to a limited ability to read the graph used in the treatment. That is, to understand the significance of the graph, one must understand the stock and flow nature of CO_2 in the atmosphere. In Moxnes (1998b), a somewhat similar information treatment showing the growth rate of a renewable resource had a limited effect for the same reason. Again the experiment points towards lack of basic knowledge about even the simplest of dynamic systems.

Fifth, the treatment with feedback, T4, asked for repeated decisions at 10 year intervals, with updated information about the CO_2-concentration before each decision. After two or three periods with this treatment, the subjects got strong indications that emissions had to be reduced to avoid serious over-expansions of CO_2. The observed effects have the expected sign in five of the six subgroups. In both IST groups the effects are significant. In the MN group the effects are small due to a limited potential for improvement from the base treatment. In the HF group the signs are as expected. While the HF effects are not significant, they are greater than the effects of the other treatments.

The effect of feedback is as expected. In fact, in many cases feedback can help correct the errors created by the use of inappropriate heuristics. This is the case if the feedback is not too much delayed and if one stays focused on the task. These two conditions are largely satisfied in our experiment. In reality they may not be satisfied. First, while feedback about the current concentration of CO_2 is frequent and precise, it does not seem to catch much attention in media. Suspected climate change effects like storms and temperature records receive much more attention. However, these effects are further delayed by the time it takes for an increased net in-radiation of heat to warm the surface of the earth (another stock and flow relationship). Long delays between the implementation of policies and the effects on total emissions further complicate simple feedback control. Second, one may suspect that people will not “stay focused on the task” when feedback is received over decades rather than over minutes. On their own, people are not highly likely to keep track of many decades of data and to reconsider previous expectations in light of new evidence.

These pessimistic comments do not preclude that information could be reformulated to give some of the positive effects observed in the experiment. The effect we have in mind is the rapid and surprising increase in the CO_2-content in spite of stabilised emissions. For instance, the following formulation could provoke similar surprises in the current debate: "In spite of emissions being nearly stabilised by the Kyoto treaty, the CO_2-concentration has (or is expected) to increase almost at the same rate as before." Such statements will challenge the truth of pattern matching heuristics, and hopefully contribute to debate and reappraisal of heuristics and mental models.

Sixth, we have already pointed out that concerns about climate change and appropriate attitudes are not sufficient to stimulate proper quantitative actions. Moreover, the fact that only the group with the strongest mathematical background (MN) showed significant effects of subject concerns, suggests that proper attitudes must be coupled with a basic understanding of the problem to yield results. An attitude, which insists that emissions must be reduced, is consistent with both a 1 percent reduction as well as a 99 percent reduction. One needs to be more precise than that. Better understanding is of course also needed for those who do not have appropriate attitudes. Attitudes are influenced by all kinds of experts and interest groups, and a basic understanding is needed to sort the good from the bad advice.

7. CONCLUSION

Climate change is considered one of the major challenges faced by mankind. Hence it is vital that countries world-wide choose emission policies that are consistent with their preferences. Similar to previous studies, our laboratory experiment shows that most people misperceive the basic dynamics of climate change and choose inappropriate policies. The main reason seems to be lack of appropriate mental models. More precisely, people have difficulties in formulating and distinguishing stock and flow representations of the system.

We tested four information treatments which all were aimed at improving people's understanding of the underlying stock and flow problem. For some groups there are positive effects of all treatments, for others the results are mixed. Judged at the 5-percent level, the results are significant only for those with the strongest mathematical backgrounds and the largest potential for learning. However, judged at the 30-percent level, 13 out of 16 information treatments in various groups show positive effects of the treatments. That should be a sufficient motivation to improve, test and make use of our information treatments in ongoing information campaigns. Even information that is only expected to have an effect on people with strong mathematical backgrounds could turn out to have unexpectedly large effects, see (Rogers 1995) on the importance of personal interactions for the diffusion of innovations and on the inhibiting role of complexity and uncertainty.

IPCC documents never speak about the discrepancy between the emission and absorption rates even though this is implicit in all the climate models. One reason may be the current uncertainty in our understanding of the carbon absorption processes. However, as long as the CO_2-concentration is observed to increase, and we have estimates of historical and current emission rates, one can produce reliable estimates of the total absorption rate. When the rate information is combined with information about the stock and flow nature of the CO_2-concentration, IPCC can argue for a shift in the focus of the debate. Less attention should be put on discussing the causes of ongoing variations in the climate, more attention should be put on the basic underlying mechanisms and the delays, as well as on quantitative measures of how large emission reductions are needed just to stabilise the CO_2-concentration. The simplified model used in this experiment may provide a good starting point.

ACKNOWLEDGEMENTS

Meltzer's Høyskole Fund, Bergen, Norway, provided the money for the subjects participating in the experiments.

APPENDIX A: Instructions for the base treatment (T0).

Please, do not touch the PC before you have read the instructions.

Burning of for example oil, gas, and coal leads to emissions of carbon dioxide and to higher concentrations of carbon dioxide in the atmosphere. The scientific community thinks that this higher concentration will lead to increasing temperatures and to climate change. The more climate change, the larger problems and costs for humans on this planet. On the other hand, reductions in energy use to limit emissions also lead to problems and costs for humans. Thus, somewhere between a too high and a too low concentration of carbon dioxide, there will be a preferred concentration which leads to the lowest total costs to humans. The challenge is to control the size of world emissions so that the concentration stabilises at the preferred level. This is the task you face, managing a simulator of atmospheric carbon dioxide.

The simulator is very simple. It keeps track of the amount of carbon dioxide that is above the level that was considered normal historically (before 1900). This amount of carbon dioxide is increased by human emissions and it is reduced by uptake of carbon dioxide in plants and oceans. To be precise, each year, 1.3 percent of this amount of carbon dioxide is absorbed by plants and oceans and thus leaves the atmosphere. Although very simple, this simulator produces almost the same development of carbon dioxide over the next century as the most advanced scientific models.

Historically, human emissions of carbon dioxide increased from close to zero in 1900 to 8.0 milliard tons per year in 2000. Due to these emissions, the amount of carbon dioxide above the historical level has increased from nearly zero in 1900 to 150 milliard tons in 2000. The numbers for 2000 define the starting point for the simulator. (In the simulator, red dot on the first graph points to this starting concentration). The preferred atmospheric concentration is 300 milliard tons, the double of the concentration in 2000. You should try to reach this goal by 2040 and keep the concentration at the preferred level the entire period from 2040 to 2100. If you stabilise the concentration at exactly 300 milliard tons you will earn NOK 120. If you on average deviate by 50 milliard tons in this period, you will receive NOK 80. The further you are away from the preferred level, the less you get paid.

The simulator works as follows. You enter your choice of the yearly emission rate for each tenth year from 2010 to 2100 in the boxes named “Emissions”. The graph shows what your choice of emission rate looks like for the entire period. You can change the numbers until you obtain the development you want. When you are pleased with the result, you click on the button called “Simulate”. The simulator will calculate the resulting concentration of carbon dioxide, and you will see how much you have earned. Remember, when you hit “Simulate” you can no longer make changes in the emission rate. To earn as much as possible, it is important that you take time to think about what to do before you click on “Simulate”.

Note that there are lower and upper limits for changes in the emissions. You are not allowed to reduce emissions by more than 15 percent in any ten years period. This may seem a small amount, however, when one remembers that world economic growth leads to higher needs for energy and emissions, a 15 percent reduction is a strong reduction. The upper limit of a 25 percent increase allows for both normal economic growth and some extra growth in emissions. If you set any emission rate outside the upper and lower limits, you get an error message.

To get your payment you must write down each and every decision you make in the decision form. When the game is over no longer touch the PC, write your payoff and sign your name on the form. After that, raise your hand and ask for the questionnaire. After filling in the questionnaire, approach the experiment leader to get your payment. Each participant will be paid privately to maintain anonymity.

Good luck, and thanks for participating!

APPENDIX B: Questionnaire.

Please answer the following questions in the sequence they are asked.

1. How old are you? ___________________

2. Gender? ____________________________

3. For how many years did you study after secondary school? ________

4. Write the number of classes you took in the following subjects. If you didn't take any classes at all, write 0.

Subject	Classes in High school	Classes after High school
Mathematics - statistics		
Science (Chemistry, Physics, Biology, etc.)		
Resource and Environment Issues		
Social Sciences (economics, sociology, etc.)		

5. For each of the statements below, please indicate whether it is RIGHT, WRONG or you are UNSURE.

Statements	R	W	U
5.1. Greenhouse effect and ozone depletion are, as a matter of fact, the same phenomena			
5.2. Chlorofluorocarbons (CFCs) are responsible for ozone depletion			
5.3. The Kyoto protocol is a treaty on climate change			
5.4. The Montreal protocol is a treaty on acid rain			
5.5. President George Bush of the United States is known to be one of the strongest supporters of the Kyoto protocol			

6. Gasses like carbon dioxide, which lead to increasing atmospheric temperatures and climate change are called greenhouse gasses. For each of the statement in the table, please enter a number between 1 and 5 according to the scale provided below:

1.STRONGLY AGREE
2. MILDLY AGREE
3. UNSURE
4. MILDLY DISAGREE
5. STRONGLY DISAGREE

Statements	
6.1. The nations of the world should make stronger reductions in emissions of greenhouse gases than they currently plan to do	
6.2. The climate change caused by greenhouse gases is not likely to be very problematic for most people of the world	
6.3. The costs of reducing emissions of greenhouse gases is very high and therefore it is better to use the money elsewhere	
6.4. We are approaching the limit of the number of people the earth can support	
6.5. The balance of nature is very delicate and easily upset	
6.6. Humankind was created to rule over the rest of nature	

7. Were you surprised by the development of the simulator? ____

8. In case you were surprised, what surprised you?

9. If you were to do the experiment over again, would you change your decisions on emissions?

10. If yes, how would you change it?

11. Explain with your own words how the simulator works.

12. Assume that carbon dioxide in the atmosphere is like water in a bathtub. Make a drawing of a bathtub where you illustrate how the level of carbon dioxide (water) in the bathtub changes, according to the instructions for the simulator.

13. How large must yearly emissions be for the amount of carbon dioxide in the atmosphere to stay constant at 300 milliard tons? (Recall that the absorption by plants and oceans were 1.3 % of the amount in the atmosphere each year)

Thank you very much for participating in this experiment and for filling in this questionnaire. Now, take this sheet to the experiment leader together with your payoff form and receive your payment.

APPENDIX C: Instructions for Physical Analogy Treatment (T1).

Please, do not touch the PC before you have read the instructions.

Consider you are inflating a balloon of the type children jump on. For this purpose you use a pump (compressor) driven by a motor. The challenge is to manage the pump so that, the balloon's air content stabilizes at a preferred level of 300 kilograms. If you pump too much air into the balloon, it will be too hard to jump on. If there is too little air in it, it will be too soft. In both cases the children may get hurt. Thus, the challenge is to manage the pump so that the amount of air in the balloon stabilizes at the preferred level. This is the task you face in this experiment: managing a simulator of the balloon. This is a very simple simulator. It keeps track of the amount of air in the balloon and this amount increases as the air is pumped in. But, note that the balloon is leaked. Each minute 1.3 percent of the air in the balloon leaks out.

When you take over the management of the balloon, it is filled to half of its preferred level, that it contains 150 kilograms of air (In the simulator, the red dot on the first graph points to this level). As you take over at time zero, the motor pumps 8.0 kilograms of air per minute. Children will begin to use the balloon 40 minutes after time zero and they will continue to use it until the 100^{th} minute after time zero. Then in this 60 minutes period, it is important to keep the amount of air in the balloon at the preferred 300 kg level. (In the simulator, the red line on the first graph depicts this target level). This is your target. In this 60 minutes period, if you stabilize the amount at exactly 300 kilograms, you will earn NOK 120. If you deviate on average by 50 kilograms, you will receive NOK 80. The further you are away from the preferred level, the less you get paid.

The simulator works as follows: You enter your choice of the pumping rate for each tenth minute from the minute 10 to minute 100 in the boxes named “pumping rate”.

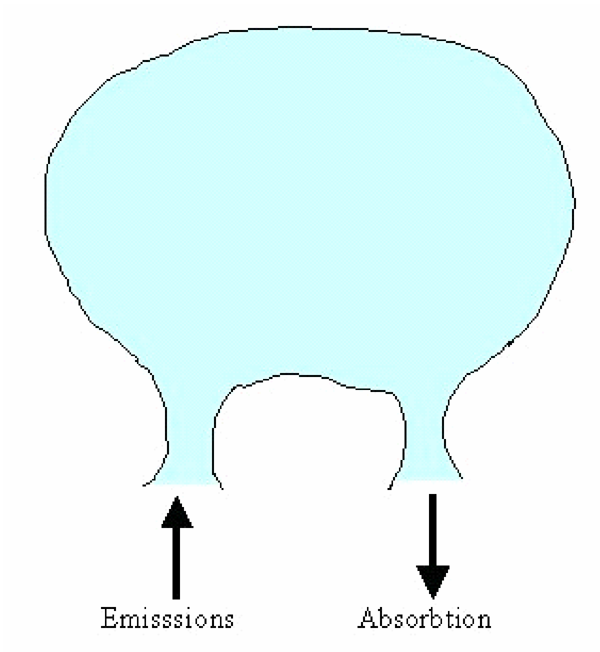
The graph shows what your choice of pumping rate looks like for the entire period. You can change the numbers until you obtain the development you want. When you are pleased with the result, you can click on the button called “Simulate”. The simulator will calculate the resulting amount of air in the balloon, and you will see how much you have earned. Remember, when you hit the “Simulate” button, you can no longer make any changes in the pumping rate. To earn as much as possible, it is important that you take time to think about what to do before you click on “Simulate”.

Note that there are lower and upper limits for changes in the pumping rate (In the simulator, these limits are shown on the last two rows of the table). Because of some technical limitations of the motor, you are not allowed to reduce the pumping rate by more than 15 percent in any ten minutes period. Similarly, you cannot increase the pumping rate by more than 25 percent in any ten minutes period. If you set the rates outside the limits shown, you get an error message under the table.

To get your payment after the experiment, you must write down each and every decision you make on your decision forms. When the game is over no longer touch the PC, write your payoff and sign your name on the form. After that, raise your hand and ask for the questionnaire. After filling in the questionnaire, approach the experiment leader to get your payment. Each participant will be paid privately to maintain anonymity.

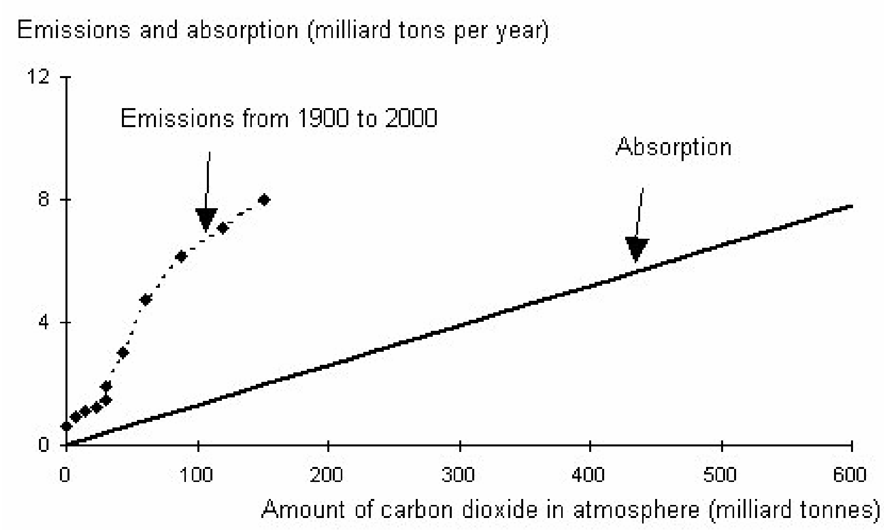
Good luck, and thanks for participating!

APPENDIX D: Supplementary Information for Balloon Information Treatment (T2)



To help you get a good result, think of the carbon dioxide in the atmosphere as being in a big balloon with two openings. Through one opening are the emissions coming in, and through the other is carbon dioxide flowing out to plants and oceans (1.3 % of the amount of carbon dioxide in the balloon each year). If more is flowing in than out, the amount of carbon dioxide in the balloon will increase. The size of the balloon will only decrease if emissions are made lower than what is flowing out.

APPENDIX E: Supplementary Information for Absorption Rate Treatment (T3)



To help you get a good result, look at emissions relative to absorption. The figure above shows how absorption increases with the amount of carbon dioxide in the atmosphere (1.3 percent is absorbed each year). The figure also shows how emissions have increased from 1900 to 2000 (the black dots denote the situation in 1900, 1910, 1920 and so on). As long as emissions are larger than absorption, the amount of carbon dioxide in the atmosphere will increase. The concentration will only decrease if emissions are made lower than absorption.

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