CONCLUSION

In conclusion, theorists now understand the cause of in-group bias to be a salient categorization rule allocating individuals into groups. A teaching exercise meant to demonstrate the in-group bias effect has been described. Data generated by this exercise are presented as evidence of the success of the exercise's procedures. Compared with other exercises that deal with the processes of intergroup relations, the "In-Group Bias" exercise has several advantages: (1) it is fun, (2) it shows an interesting and robust effect, (3) it requires little preparation and few materials, (4) it can be used with almost any number of participants, and (5) it can be completed in a 50 minute time period. Nevertheless, an instructor who wishes to use the exercise should keep in mind the following cautions: (1) an attendance or class list must be available, (2) the room must have moveable chairs, (3) the instructor must have a pocket calculator and be able to calculate means and standard deviations, and (4) with groups of 30 or more participants, two instructors may be needed to coordinate the exercise, one to lead the debriefing while the other calculates the results.

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A GAME FRAMEWORK FOR SCENARIO GENERATION FOR THE CO_2 ISSUE

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Increasing atmospheric CO_2 from widespread burning of fossil fuels may lead to changes in global climate, with impacts on society and environment. Gaming may be a useful means for structuring and learning about this issue. A group at the International Institute for Applied Systems Analysis (IIASA) has explored several possible CO_2 games. A framework built around impacts of climatic change, scientific uncertainty, external factors, and policy options of prevention, adaptation, and compensation is described in this article. The framework is designed to raise questions of what could happen to whom, when, and to what effect. An appendix lists background information for the framework.

The overwhelming proportion of energy that people use now comes from the burning of fuels containing carbon: coal, oil, gas, and wood. When these fuels are burned, carbon dioxide (CO_2) is released to the atmosphere.[1] CO_2 is a "greenhouse" gas: it lets energy into the atmosphere more freely than it lets it out. Thus, when CO_2 in the atmosphere increases significantly, the atmosphere near the surface of the earth is likely to become warmer.

There is growing concern that if over the next 50 to 100 years people continue to increase their use of carbon fuels, especially the abundant resources of coal, the global climate may become much warmer. Quite different patterns of climate could occur in many regions. Such changes could mean substantial shifts in

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natural and environmental endowments for nations, regions, industries, and individuals. While the changes could be beneficial, they could also have tragic consequences; especially in a heavily populated world where competition for land and water resources is already great.

Is this large-scale geophysical experiment a social trap? Will we accelerate towards it, or will it cease to be serious for one reason or another? The CO_2 question has remained a vexing one through recent years. Partly this is because of large scientific uncertainties. Partly, it is because of inadequate efforts to explore particular facets of the issue, like the character of a greatly expanded carbon economy and the impact of climate on human activities and the environment. Not least, it is because of failures to link these various aspects of an assessment together and to face questions of possible societal responses.

Information on the CO_2 question and climatic change remains widely scattered. Efforts to integrate, to describe plausible sequences of how climatic change of CO_2-related events will unfold, have not been very successful. Some recent efforts are those by d'Arge et al. (1975), MITRE (1977), SRI (1977), National Defense University (1978), Aspen (1980). Research that gathers and synthesizes information and puts both findings and uncertainties in perspective remains greatly needed. As long as a more definitive method of assessment of the CO_2 issue is lacking, there may be a role for analysis of "scenarios," or reasonable, coherent, sometimes qualitative depictions of projected developments (Epple and Lave, 1980). However, a single detailed scenario may be as misleading as illuminating (AAAS, 1979). Too often the single scenario is treated as a prediction.

Gaming appears to offer a flexible way to generate and explore CO_2 scenarios. A game can simulate a CO_2 scenario by creating a sequence of possible events associated with development of the carbon economy and climatic change. Arguments for the use of a gaming approach have been presented in fuller form elsewhere (Ausubel et al., 1980), and only the broad rationale will be repeated here.

To judge from our initial experience, gaming offers three broad categories of benefits. One is that the construction of the games is enlightening as an exercise in model building. Game development stimulates collection and organization of information. For this game, it requires an attempt to integrate formally the carbon economy, functioning of the carbon cycle and the climate system, and the impacts on society of increased concentrations of CO_2 and altered patterns of climate. Figure 1 presents the basic conception of the CO_2 issue that was developed for the gaming approach.

The second category of benefits is that a gaming approach can offer insights into strategic and behavioral aspects of the issue. For example, presence of human players encourages consideration of the strategic behavior of nations with respect to their energy policies. Will coal cartels tend to form? At another level is the question of which aspects of climatic change are perceived as posing serious risks. The third type of benefit is educational. Along with what the game designers learn from construction and play of a game, players learn about the issues at hand.

Several games with various purposes, levels of complexity, and substantive emphases have been explored by an informal carbon and climate gaming group at the International Institute for Applied Systems Analysis (IIASA).[2] One game, a simple Monopoly-style board game emphasizing educational objectives, has already been completed and played several dozen times with groups at scientific conferences, research institutes, universities, and schools. The board game, entitled "The Greenhouse Effect," tries to impart a small number of key features of the CO_2 issue: the potential tragedy of the commons, the great uncertainty, unequal distribution of costs and benefits, time lags and irreversibility, and the interdisciplinary nature of the problem. A more complex, computer-based game focusing on the coal industry and world coal trade in relation to CO_2 is also nearing completion.

Rapoport's (1981) review of research on commons and prisoner's dilemma situations reports that people are more likely to control impulses to pursue private gains to the detriment of a collective goal if they can exert pressure on each other through communication, if the dangers inherent in pursuit of short-term gains are manifest, and if improvident decisions impair their own long-term well-being. The computer-based coal game stimulates

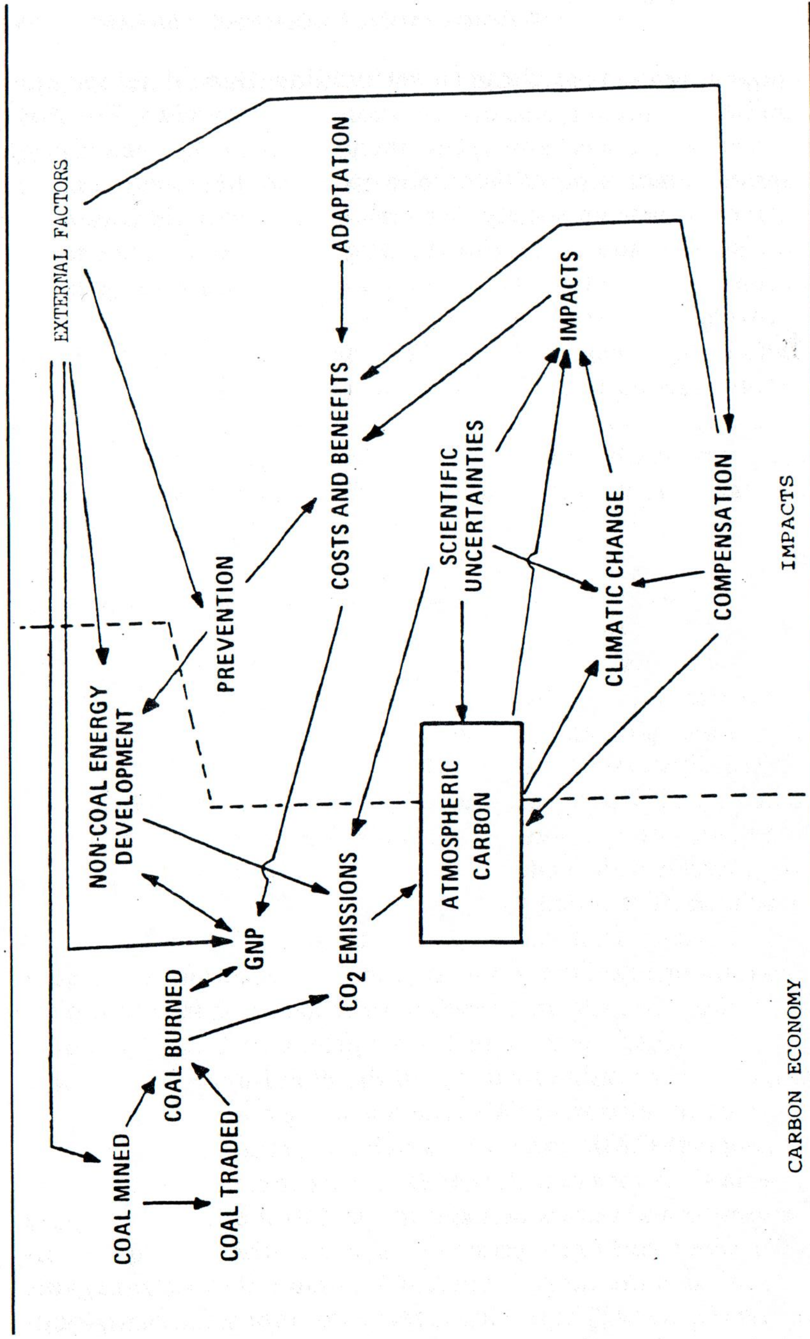

Figure 1. Basic conception of the CO_2 issue for the gaming approach

understanding and the research of issues concerning occurrence of cooperative and noncooperative behavior. A third gaming approach, described in the remainder of this article, is directed more toward a better conceptualization of an issue. It should be regarded as a game to help improve design of research on societal consequences of, and responses to, increasing levels of CO_2. It is intended to raise basic questions about what could happen to whom, when, at what expense, and to what effect.

THE FRAMEWORK FOR SCENARIO GENERATION

BOARD LAYOUT

The framework is visually centered on a picture of the atmosphere gradually holding more and more carbon. For practical purposes, this can be pictured as a board or screen. As play progresses, players emit carbon into the atmosphere, and the atmosphere board fills up with marks or chips representing carbon. Events are triggered by play at different levels of atmospheric carbon.

Atmospheric carbon, measured in gigatons of elemental carbon (one gigaton = one billion metric tons, and is abbreviated gT C), has been chosen as the main index because it is the central physical parameter of the CO_2 question. The position of atmospheric carbon is an important feature of the framework. Neither our forecasts nor our scientific understanding of the CO_2 question are secure enough to specify at what time various events will occur. Despite this uncertainty, it may be more reasonable to link certain events to certain levels of CO_2. For example, impacts of climatic change and policy measures that might be used to prevent, compensate for, or adapt to CO_2-induced climatic change might be tentatively indexed to levels of CO_2; Some events may seem likely to occur around a 50% increase, some around a doubling, and some around a tripling of the level present in the atmosphere.

The board is a common. Each player, when taking a turn, registers the emissions for one period of economic activity on the board and thus changes the state of nature for all players. The format is a variant of the "Tragedy of the Commons," in which potential costs and benefits are not known in advance and are unevenly distributed among players.

The following section describes the atmosphere board, its scale, what is on it, and how it can operate. It is followed by a sample exercise.

SPACES AND BLOCKS

Our first version of the board consists of 1600 numbered "spaces," each representing 1gT C. These spaces are numbered from 600 gT, the estimated weight of carbon in the atmosphere before the industrial revolution, to 2199 gT C, about a tripling of current (1982) values. Thus, the board shows a range of atmospheric carbon values which imply a significant warming. A doubling of present atmospheric carbon suggests an increase in global mean temperature of about 2 to 3.5 degrees centigrade. Even with conservative assumptions, a tripling seems likely to lead to a warming which could be associated with significant changes in the Antarctic ice cover and possible changes in sea level.

The game begins at the current level of a little over 700 gT C; but the board begins at 600 gT C in order to suggest the consequences of economic activity of the past century and to contrast the past rate of emissions with that in the present and future. In this way, if exponential growth continues, the board will graphically show the rapidity with which the absorptive capacity of the atmosphere is used.

If the board is to represent 1600 gT C, a 40 × 40 square matrix is convenient. As indicated, each cell of this matrix is referred to as a space. Referring to 1600 spaces can be clumsy, so the spaces are organized into 16 blocks of 100 spaces each. We will refer to these by values of atmospheric carbon, the first being the 600 gT block, the next, the 700 block, and so forth. This division gives the board a layout as shown in Figure 2.

The size of units within a block should be sufficiently small to describe the amounts players can be expected to be emitting. It could be varied, depending on whether players were representing the globe, regions, or nations, and whether game decisions are made on a one, five, or ten year basis. As a first experiment, we have adopted a resolution of one space per gT C. This is simple, and provides fine enough resolution to show carbon added under various situations that are interesting for simulation. It would be adequate to show one global player making decisions on an annual basis. (Current global carbon emissions are estimated to be a little over 5 gT C per year, of which about half appears to remain airborne). This resolution would also be appropriate for a gaming situation with large and medium sized nations making calculations of emissions on a 10-year basis. To develop the module for more players and different time periods, the number of blocks could be changed or the spaces could be rescaled or subdivided.

*1 600	*2 700	800	900
1000	1100	1200	1300
*3 1400	1500	1600	1700
1800	1900	2000	*4 2100

Figure 2. Block layout of atmospheric board. *1 indicates the pre-industrial level of CO_2; *2 the current level, *3 the doubling level, and *4 a tripling.

TYPES OF SPACES

Each of the spaces is associated with what we shall refer to as an "event." In fact, these may be not only events, but also various kinds of opportunities, processes, or trends. An event happens when the number of gT C in the atmosphere equals the number of the space on the board. Expanding on the work of Meyer-Abich (1980), six kinds of events are distinguished. These are:

(1) *Impacts of climatic change* (I). These are spaces that describe the impacts of climatic change and increased CO_2 concentrations. They include impacts on agriculture, water resources, health, and so forth. These can be positive or negative, according to the player's location on the board, and a chance variable. Impact spaces may affect one or all players posing as nations, and may affect different players differently. While called "impacts," the role of these spaces in the game is not unidirectional, as costs and benefits arising from them affect the economic base from which other decisions are made.

(2) *Opportunities for Adaptation* (A). On these spaces players can purchase adaptive measures that will mitigate later adverse impacts of climatic change. Early on there are opportunities to purchase assessment reports, and sponsor CO_2 research. Later there are opportunities to make agricultural systems more resilient by developing drought-resistant crop strains, to redesign hydrologic systems so as to buffer against changes in precipitation, and the like.

(3) *Opportunities for prevention* (P). On these spaces players are offered means for reducing carbon emissions by preventing them at the origin, that is, by changing economic activity so less CO_2 is generated in the first place. For example, there are opportunities to invest in conservation, nuclear, solar, and hydro-energy, and to explore for natural gas, which emits less CO_2 per unit energy than other carbon fuels.

(4) *Opportuniies for compensation* (C). Here players, having allowed generation of CO_2, can take measures either individually or cooperatively to reduce levels of atmospheric carbon or other measures that physically compensate for climatic change. These include planting trees to increase biotic CO_2 removals, and engaging in weather modification.

(5) *Resolution of scientific uncertainties* (S). On these spaces findings are provided for various natural and physical questions.

For example, information is offered about: how precipitation change associated with CO_2 increase will be distributed; the amount of heat and carbon the oceans can absorb; and, to what extent other trace gases such as N_2O and chlorofluorocarbons will compound the greenhouse effect.

Resolutions of scientific uncertainty raise an interesting issue. Realistically, they should affect the players' knowledge of the rules by which the game is being played, and not the rules themselves. By affecting players' knowledge, the resolution of the scientific controversies may have various effects that need not be prescribed in the event spaces. For example, if resolution of scientific uncertainty shows that a player's agricultural lands will become arid, the player may then perceive that he has an increased interest in reducing global emissions. How he uses this information is up to him.

(6) *External factors* (X). On these spaces events occur that are not directly part of the carbon cycle nor climatic change, but which can significantly impinge on the well-being and policies of the players. They include depression, war, strengthening of international institutions, technological breakthroughs, and so forth.

A sample listing of approximately 80 events grouped into the six categories is presented in the Appendix of this article. A major task for CO_2 research is to expand information on events that are relevant to specific countries, stated in terms of appropriate frequency of appearance at various levels of atmospheric carbon, and in terms of magnitude in monetary or other terms.

DISTRIBUTION OF EVENT CATEGORIES

It is clear that a key issue in the construction of the games or any scenario-oriented exercise is the sequence of events and types of events to be faced in each period. It is difficult to associate events or opportunities directly with time periods, such as the decade 2020-2030, because we do not know in advance of playing the game at what rate emissions will occur. However, it may be possible, though highly speculative, to associate different events and opportunities by probability with different levels of carbon in the atmosphere. In the game this is equivalent to the distribution of event categories within any block of the atmospheric carbon board. While recognizing that not every space will be encountered, one should be able to propose that each block might be characterized by, for example, a preponderance of impact spaces or perhaps of spaces where scientific uncertainties are resolved.

Both distribution of events and costs and benefits associated with them will vary as atmospheric carbon increases. For example, in the 700 block, impacts are few and inconsequential, and opportunities for prevention are relatively abundant. By the 1400 block, with double the present values of atmospheric carbon, impacts should be significant; deserts may be turned to cropland, cropland to desert, tundra to boreal forest, and icefields into open ocean. Clearly, a variety of changing distributions of spaces might be proposed. Figure 3 shows overall distribution patterns for each category of event and possible relative shares of spaces over the proposed range of atmospheric carbon.

IMPACT SPACES

Impact spaces barely appear before the 900 block. Before that time climatic phenomena are of normal dimensions, and in any case, human-induced effects can hardly be distinguished from natural variation, since the CO_2 signal-to-noise ratio is low. Around the 1000 block, roughly 50 percent more carbon is in the atmosphere than at present, and impacts begin to become more pronounced and attributable to CO_2. Their frequency and the amount of attention given to them increase until the 1400 block which is a doubling of present levels. After that point, society would be accustomed to anticipating climatic change and attention to the CO_2 problem would level off. After this, the number of impact spaces declines slightly, under an assumption that the magnitude of impacts may increase, but the kinds of impacts will not. However, at very high levels of atmospheric carbon it may be that the frequency of impact spaces would again increase, when new possibilities like an ice-free Arctic and a collapse of the West Antarctic ice sheet increase in probability.

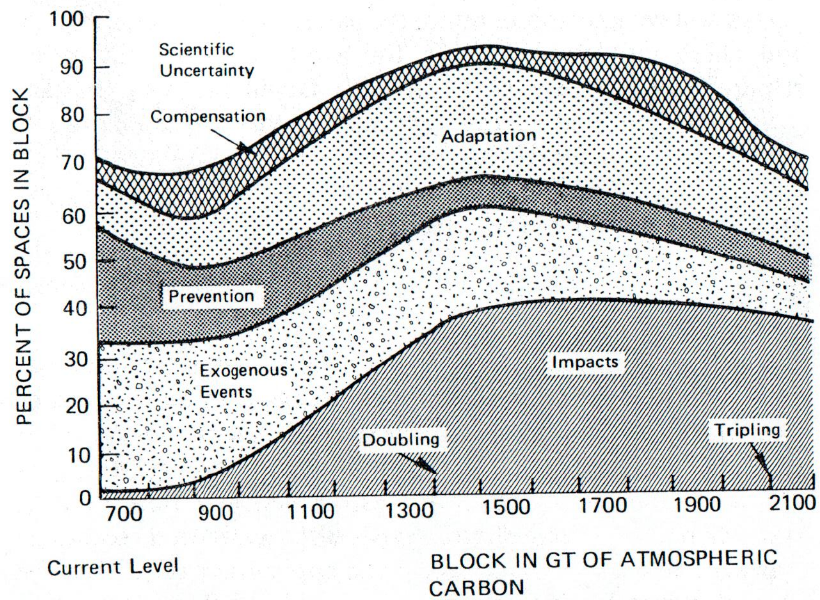

Figure 3. Hypothetical frequency of occurrence of game event categories (cumulative shares).

ADAPTATION SPACES

Adaptation spaces exist at a steady level at the beginning. These early spaces would mostly consist of opportunities for research and for building resilience. As the level of atmospheric carbon rises, and impacts begin to occur, ways to adapt become more apparent, and more opportunities for adaptation appear. As the level continues to rise, possibilities for adaptation remain quite high but lag behind the multitude of impacts. When the problem has been around for a long while, societies become more attuned to changing climatic regimes, and new opportunities for adaptation diminish. The overall pattern of adaptation bulges in an indication of transition or adjustment costs.

PREVENTION SPACES

Prevention spaces are common in the beginning of play, while the successor to the oil economy is being nominated and incorporated into social and economic infrastructures. Once new energy sources gain momentum, the pattern becomes less flexible, and there are fewer options for averting CO_2 buildup by relinquishing the use of fossil fuel. Given the long market penetration times of energy systems, it seems reasonable that if choices are not made by the time the level of atmospheric carbon increases by about 50%, fewer opportunities for prevention will arise, and they will be less effective.

COMPENSATION SPACES

Compensation spaces are always present, but never common, due to strong constraints on this strategy. Initially, lack of mechanisms for international cooperation and pressures for the use of the biosphere for food, firewood, and fiber, limit opportunities. However, as the CO_2 question becomes more serious, new chances for biospheric (especially terrestrial) solutions appear. These will be no longer on an appropriate scale once the level of atmospheric carbon becomes high, so the spaces again become infrequent. At very high levels of carbon emissions and atmospheric carbon new opportunities arise, as technological solutions such as gigamixer or methane capture gain greater consideration.

SCIENTIFIC UNCERTAINTIES

Resolution of scientific uncertainties is extremely important during the first 300 gT increase in atmospheric carbon. In the 700, 800, and 900 blocks, the signal-to-noise ratio increases, and scientists will be able to answer questions they are now asking about atmospheric and carbon cycle behavior. Subsequently, the frequency of this category of event diminishes drastically. At the doubled level, the climate behaves in accord with the state of nature set by these early resolutions. At very high levels, new uncertainties arise, particularly in relation to the West Antarctic ice sheet and rising sea level.

EXTERNAL FACTOR SPACES

External Factor spaces are most frequent early on, since at the beginning of the game the CO_2 problem is relatively unimportant for national and global development and easily dominated by other events. As atmosphere carbon increases, and the physical situation changes more and more from its present state, the relative importance of CO_2-related events and decisions grows. At high levels of atmospheric carbon, external factors become infrequent in the game.

USING THE FRAMEWORK

GNP(t) = (GNP(t−1) − nb(t−1)) * eg(t)
GNP(t) = gross national product in given time period
nb(t) = net of costs and benefits from events (I spaces, etc.) of time period
eg = economic growth factor (for example, 1 + growth rate in percent)

CE(t) = GNP(t) * cr(t)
CE = carbon emissions (gT)
cr = carbon to real GNP ratio in gT C emitted per trillion dollars

cr(t) = cr(t−1) * pe(t) * f [tb (t)]
pe = prevention effect
tb = technological breakthrough from external factor (X) spaces

pe(t) = g[pe(t−1), pp(t−1)]
pp = prevention purchases from P space opportunities

AC(t) = AC(t-1) + (CE(t) * a)
AC = atmospheric carbon (gT)
a = fraction of emissions remaining airborne

As indicated above, the ratio of carbon emissions to GNP may vary from the historically existing values through prevention measures, such as adoption of nonfossil fuel strategies (P space purchases) or through technological breakthroughs coming from X spaces. Prevention effects and effects from technological breakthroughs are carried over into the next time period. How to establish GNP growth rates remains a question. The rate of change could be held constant; the growth rates could be changed by players' decisions; they could take a random form, obtained by spin of a wheel or, in computerized version, by use of a random number generator. A multiplier needs to be devised to represent increasing costs and benefits for impacts spaces as the atmospheric carbon level increases.

A SAMPLE EXERCISE

This section presents an example of how the framework might operate using the extremely simple model described above. The numbers in what is sketched here are obviously not research findings; rather the immediate effort is to identify what elements are needed in a model, what data are desired, and to acquire experience in scenario generation and exploration.

The exercise uses one of the framework's sixteen blocks, the 1000 block, which corresponds to an atmospheric CO_2 level about 50% higher than today. A tentative board layout for this block is shown in Figure 4. The letters and subscripts in the 100 spaces on the board refer to the events listed in the Appendix. For example, S_4, the last space in the block, refers to Scientific Uncertainty #4, human influences on climate other than CO_2. The frequency of types of spaces (I, A, P, C, S, X) corresponds to that shown in Figure 3. Of course, not all the events listed in the appendix are included in the 1000 block. Because there are no serious predictions that the West Antarctic ice sheet will collapse because of a warming induced by this level of CO_2, the impact space representing this event does not appear in the block. The order of events within the block is largely random. For example, S_4 could as easily be in the first or the fifty-second space, as in the last.

For simplicity of presentation and accounting here, the exercise is conducted with only one player, who represents a single global decision-maker. One-year time periods are used. The economic growth factor is determined by the spin of a hypothetical dial and may range from 1% to 4%.

For the sake of starting calculation, let us assume that the year is 2005, that gross world product (GW) in 2004 was 16 trillion

1000 P_{10}	1001 S_1	A_2	C_1	I_{10}	S_4	P_5	C_2	X_1	1009 I_9
S_3	X_2	C_1	P_3	X_3	I_4	S_5	P_2	X_{13}	S_2
X_5	X_4	A_2	S_1	C_2	P_7	P_1	A_3	A_6	S_5
S_4	C_3	X_{16}	I_1	X_6	S_3	A_7	X_{12}	C_1	I_5
X_{18}	S_8	A_1	P_9	S_2	C_1	P_6	X_7	S_7	S_2
S_4	P_4	X_{13}	S_3	X_8	S_1	A_7	I_{18}	P_7	A_5
A_4	I_3	A_6	P_3	X_9	S_7	C_5	X_{13}	P_1	A_8
P_2	X_{10}	A_5	X_{11}	I_6	I_7	X_{12}	A_1	S_4	S_1
S_3	A_7	X_{14}	S_2	X_{10}	X_{15}	A_4	I_2	X_{17}	A_8
P_8	S_4	I_6	X_6	S_3	I_{11}	X_2	C_4	X_9	1099 S_4

Figure 4: Example of possible layout for the 1000 block of the atmosphere board.
NOTE: 12% of the spaces are impacts (I), 25% external factors (X), 24% scientific uncertainties (S), 14% prevention (P), 9% compensation (C), and 16% adaptation (A).

dollars, the carbon emission to GWP ratio (cr) is at .75 gT per trillion dollars, and the fraction of emissions remaining airborne (a) is 0.53. (For comparison, in 1975, actual GWP was about 6 trillion dollars and the carbon emission to GWP ratio was around 0.8). Let's say that net costs and benefits (nb) from 2004 to 2005 were +25 trillion dollars (between 1% and 2% of GWP), and a spin of a dial indicates that GWP growth (eg) is 3%.

Using the equations from the previous section:

$$GWP(2005) = (GWP(2004) - nb(2004)) * eg = (16 + 0.25) * 1.03 = 16.74$$

$$CE(2005) = GWP(2005) * cr(2005) = 16.74 * 0.75 = 12.55$$

$$AC(2005) = AC(2004) + (CE(2005) * a) = 1000 + (0.53 * 12.55) = 1006.65$$

This puts the counter on space 1006, where card P_5, an opportunity to prevent emissions by instituting a carbon tax, turns up. Suppose the player decides to purchase reduction of the carbon emission ratio (cr) of 0.5 percent per year for five years at a cost of 50 billion dollars per year. Pretend also that the next spin of the economic growth dial gives a factor of 2%. The next round of calculations goes as follows:

$$GWP(2006) = (GWP(2005) + nb(2005)) * eg = (16.74 - 0.05) * 1.02 = 17.02$$

$$cr(2006) = cr(2005) * pe(2006) = 0.75 * 0.995 = 0.74625$$

$$CE(2006) = GWP(2006) * cr(2006) = 17.02 * 0.74625 = 12.70$$

$$AC(2006) = AC(2005) + (CE(2005) * a) = 1007 + (0.53 * 12.70) = 1013.73$$

The counter thus moves to space 1013, where the player draws card P_3, an opportunity to reduce carbon emissions by searching for new sources of natural gas. Suppose the global player decides to invest 100 billion dollars and finds that the investment permitted reduction of the carbon ratio by only 0.02%. (If the results of drilling are uncertain, there should be a range of outcomes possible for spaces like this.) The next spin of the dial shows an economic growth factor of 4%. Including the costs and reductions in emissions ratio from the carbon tax instituted in the year 2006, calculations proceed:

$$GWP(2007) = (17.02 - 0.05 - 0.10) * 1.04 = 17.55$$

$$cr(2007) = 0.74625 * 0.995 * 0.998 = 0.7410$$

$$CE(2007) = 17.55 * 0.7410 = 13.00$$

$$AC(2007) = 1014 + (13.00 * 0.53) = 1020.89$$

The board is now filled to space 1020, where card X_5 is found. X_5 informs the player that there has been a significant breakthrough in generation of electricity through fusion, with an initial capability to reduce the carbon emissions ratio by 1%. A spin of the dial indicates economic growth at 2%. Thus, still carrying over the costs and benefits of the carbon tax:

$$GWP(2008) = (17.55 - 0.05) * 1.02 = 17.85$$

$$cr(2008) = 0.7410 * 0.995 * 0.99 = 0.730$$

$$CE(2008) = 17.88 * 0.730 = 13.03$$

$$AC(2008) = 1021 + (0.53 * 13.03) = 1027.91$$

This moves play to space 1027, where A_3, the card for offensive contingency plans, comes up. This card permits the player to invest to take advantage of market dislocations caused by climate change. In a multiple player situation, this might allow the player whose turn is taking place to profit the next time a negative CO_2 impact appears for another player. It may be inapplicable to the global player situation.

Clearly, major design questions for the game remain open, and new ones would appear with continuing use of the framework. For example, might some other format be better? Should the board the players see be blank; should they see only the designation of space categories, or should the exact nature of the spaces ahead be revealed? Should players be able to see that space 1020 holds a powerful technological breakthrough; should they know only that it is an external factor, or should they be given no clues at all as to what is there? Is a player confronted with policy decisions each turn, or only when his carbon emissions land him on a P, A, or C space? Definitive resolution of such design questions is not planned; on the contrary, the idea is to have a framework that stimulates wide-ranging consideration of the structure of the issue. Players and readers are encouraged to rearrange and to reframe information as they find it useful.

CONCLUSION

The goal of the framework as described here is not realism in the sense normally sought by physical or economic models. There is no intent to predict. The goal is qualitative, along the lines of an exercise in painting: here is a canvas, a few rules of perspective; here is a palette with several colors. The exercise should suggest the need for more imaginative attacks on the generation of scenarios. There is a need for ones that raise fundamental questions of probabilities of events, sequence of events, relative importance of particular events to particular players, interactions among events, and so forth. Coherent schemes for organizing information about the CO_2 issue are conspicuously lacking. It is hoped that the framework described here is a stimulus for suggesting complexity and structure in a situation about which the uninitiated or those with narrow disciplinary backgrounds tend to think in simplistic or chaotic terms.

APPENDIX

This appendix offers a listing of about 80 topics which might be represented in the six event categories. With respect to each topic, players might consider one or more of several question.

(1) What role should this have in the game? Is the event in the proper category? Is it properly formulated?
(2) For which countries or regions is this relevant? As Meyer-Abich (1980) has pointed out, different options may in many cases turn out to be options of the different parties involved, so that the question is whether country A takes a step for prevention, or whether country B takes a step for adaptation. International activities for compensation may also be viewed differently by the different parties involved. For some countries (or biomes) reforestation may be relevant, and impacts in northern ecosystems are important for certain countries and not for others.
(3) Over what range of atmospheric carbon is this event likely to become frequent, important, or prominent? After small increases? After a doubling? A tripling? Can other comments about timing be made? Is the event a sudden one, or is it a process occurring over a long span of time?
(4) What costs or benefits may be involved with this event? Can this be formulated in monetary terms (for example, as a percentage of GNP) or in some widely applicable quality of life indicator?
(5) How effective or powerful is the event or measure? This might be assessed by its potential reduction of carbon in the atmosphere (in gT C) or in monetary terms.

IMPACTS

I_1: Estuaries and Salt Marshes.

Small changes in climatic conditions over continental areas may manifest in coastal areas, due to the delicate nature of the estuaries and salt marshes. Impacts could include a change in biological productivity and community structure along the coastline.

I_2: Northern Ecosystems.

The greatest temperature change is expected to be at the poles, so northern ecosystems may change considerably and in advance of equatorial systems. This could provide agricultural opportunities, but the soils may be poor and the ground swampy.

I_3: Weather Stress on Economic Crop Plants.[3]

One of the ways climatic change is likely to manifest itself is through changes in extremes and in "weather stress." There could be record floods and hail, but there could also be fewer frosts.

I_4: Fresh Water Ecosystems.

Shallow water bodies are particularly sensitive to variability and change of climate. Lake shores may expand or contract, and certain streams and rivers may also change in character dramatically.

I_5: Tundra and Terrestrial Cryosphere.

Engineering problems could increase or decrease in areas that have permafrost on land and ice offshore. Mineral extraction, transportation, and tourism may be affected.

I_6: Water Resources.

The quantity and quality of water resources could improve or worsen.

I_7: Grazing Land and Animal Husbandry.

Pastures may improve; animals may suffer from higher temperatures.

I_8: Aesthetics and Landscape.

The character of the landscape is changing. Wherever people live green meadows are drying out, woods turning to bog or grassland. National parks are losing the beauty for which they were preserved. Many homeowners, tourists, and environmentalists are unhappy.

I_9: Species Extinction.

Natural species are finding themselves in climates to which they are not adapted. Desiccated landscapes may suffer severe fire. Some species are migrating; others are becoming extinct. Economically valuable genetic material may be lost.

I_{10}: Broad Climatic Impacts on Agriculture.

Agricultural production may be dramatically altered in many areas.

I_{11}: Plant Protection from Pests and Pathogens.

There may be significant increases in the magnitude of problems associated with the protection of plants from pests and proliferation of weeds. Colder weather and frosts may have offered protection.

I_{12}: Ocean Biota.

There could be more or fewer fish, and beneficial or harmful impacts on the marine food chain. The shifts in location of stocks may be advantageous to some and not to others.

I_{13}: Soil Organic Matter.

Temperature rise accelerates oxidation of soil organic matter; especially under intensive soil cultivation practices, and in regions with fragile soils.

I_{14}: Managed Forests.

Rotation time in forests may be shortened, enabling higher production of wood and pulp products. New pests or water deficiencies may outweigh the benefits of this.

I_{15}: Photosynthesis and Productivity of Crop Plants from CO_2 Increase.

There should be increased growth from CO_2 fertilization, and there will be a variety of impacts on species' life cycles, phenologies, and yields of usable product.

I_{16}: Heating and Air-Conditioning.

Space heating and air-conditioning requirements may increase or decrease.

I_{17}: Arctic Sea Ice.

The Arctic sea ice may be reduced, and it may begin to disappear seasonally, or even on a lasting basis. This may increase the possibility of mineral extraction in the Arctic, and its usefulness for transportation.

I_{18}: Migration.

There could be large climate-induced population movements, both internally and between nations, and the adjustment costs and political stresses arising from these may be huge.

I_{19}: Problems of Location.

Some facilities will no longer be located in appropriate places. Relocation, capacity expansion, new industrial development may involve added costs because of climate change. Since infrastructure is adapted to the present climate, benefits seem less likely than costs.

I_{20}: Visibility and Other Air Quality Issues.

Changing the climate may alter many other attributes of the atmosphere at the regional and local level. Areas famous for limpid skies may become hazy, while areas with formerly sluggish air circulation may have fresh winds to blow their pollution away.

I_{21}: Efficiency of Water Use in Plants.

CO_2 enrichment increases the ratio of photosynthesis to transpiration. A 10 percent increase in water use efficiency could come with a doubling of atmospheric CO_2.

I_{22}: Human Health.

Climate may become more pleasant, or higher temperatures and greater frequency of extreme episodes may have negative health impacts. Extended exposure to higher levels of CO_2 may have a variety of biomedical consequences.

I_{23}: Imminent Collapse of the West Antarctic Ice Sheet.

The sea level could rise five or more meters within a few centuries. Low-lying coastal areas, including many of the world's major cities and major river deltas, would be submerged.

I_{24}: Hydropower Systems.

The yields of watersheds may change so that hydroelectric plants work below capacity, or it may be possible to add new turbines.

I_{25}: Solar Energy Systems.

The timing and percentage of cloud cover may change to affect solar energy potential.

I_{26}: Non-CO_2 or Climate Health Effects of Coal.

Substantial increases in mining and burning of coal may have strong consequences for occupational safety and health and for air quality.

ADAPTATION

A_1: Assessment Reports.

The first step people can take is to study the problem. Sponsor research, try to narrow uncertainties.

A_2: Stockpiles.

Build buffer stocks, for example, of grains. Use stockpiles to protect oneself and to speculate against others.

A_3: Offensive Contingency Plans.

When you foresee that climate change will create market disruptions, you can invest in capacity to produce goods and services that will be in short supply.

A_4: Insurance.
Financial instruments and institutions can protect against risks threatened by climatic change and increase opportunities for gain.

A_5: Climate Extension Work.
Enhance institutions that work with agriculturalists and climate-sensitive industries so that they are better prepared to adapt to changes in climate and weather.

A_6: Emergency Preparedness.
Invest now, for example, to increase civil defense against natural hazards like severe storms.

A_7: Civil Works.
Reinforce dams, for flood protection, and increase irrigation potential to protect against drought.

A_8: Agricultural Research.
Develop crop strains that are less sensitive to climate and can take advantage of increasing atmospheric CO_2.

PREVENTION

P_1: Solar Energy.
Give greater emphasis to solar technologies for heating, generation of electricity, and production of fluid fuels for transportation.

P_2: Conservation.
Incentives for energy conservation are increased, partly because of the high capital costs of energy development.

P_3: Natural Gas.
Natural gas emits less CO_2 per unit of energy than other carbon fuels. Provide assistance in exploration for and exploitation of natural gas reserves, especially in less populated regions where modern geological and geophysical methods have just begun to be used.

P_4: Conventional Nuclear Power.
Pursue rapid expansion of conventional (nonbreeder) nuclear power.

P_5: Carbon Tax.
Institute a carbon tax to encourage a shift to nonfossil and cleaner fossil fuels.

P_6: Improve Land Use.
Slow down the expansion of agriculture into forested lands and introduce improved sylvicultural practices.

P_7: Breeder Reactors.
Encourage development of nuclear power, especially breeders.

P_8: Hydro.
Subsidize capital for development of hydroelectric power.

P_9: Biomass.
Encourage development of biomass fuels.

P_{10}: Local Generation.
Substitute small-scale dispersed generation of electricity, using locally available sources, for large-scale centralized generation.

P_{11}: Carbon Residuals Permits.
Create a market in CO_2 permits to limit use of coal and other fossil fuels and make emissions much more costly.

P_{12}: Liability.
Governments and judicial systems might accept the principle of assigning liability for damages on account of climatic change. Everyone dreads litigation except the lawyers, so it is a way to reduce emissions.

P_{13}: Ambient CO_2 Standards.
You can adhere to the Global Environmental Protection Agency which has just set the standard.

COMPENSATION

C_1: Reforestation.
Decrease atmospheric carbon by planting millions of fast-growing, long-lived trees that are left unharvested.

C_2: Soil Carbon Banks.
Decrease atmospheric carbon by growing short-lived plants which are converted to humus and allowed to accumulate in artificial peat bogs.

C_3: Biological Transfer of CO_2 to Deep Ocean.
Supply phosphates and nitrates to surface waters to fertilize growth of marine organisms. These will incorporate carbon and eventually sink and settle safely on the ocean floor.

C_4: Physical Transfer to Deep Oceans.
Limit atmospheric carbon by piping CO_2 to places in the oceans where currents will carry it to deeper ocean waters where the CO_2 will remain for centuries.

C_5: Methanol.

Take atmospheric CO_2 and convert it to synthetic liquid and gaseous carbon fuels using a nonfossil energy source, such as nuclear or solar.

C_6: Weather Modification.

Weather and climate modification (cloud seeding, changing albedo) and other human actions outside the carbon cycle may become a way to compensate for what increasing CO_2 is doing.

C_7: Icebergs.

Compensate for decreases in water supply by large-scale imports of water, for example, by floating icebergs from the Antarctic or by schemes to transfer waters from one river basin to another.

SCIENTIFIC UNCERTAINTY

S_1: The Airborne Fraction.

Between one-third and two-thirds of the carbon injected into the atmosphere is continuing to remain there. The size of this fraction makes a big difference in how soon high levels of CO_2 are upon us.

S_2: Clouds.

Changes in cloudiness and other radiative features of the atmosphere may increase or decrease CO_2 effects in ways we have not anticipated.

S_3: Ocean Thermal Buffering.

The oceans may or may not absorb and distribute heat from the atmosphere at rates currently calculated.

S_4: Human Influences Other Than CO_2.

Other trace gases (chlorofluorocarbons, or oxides of nitrogen) emitted by human activities, as well as other man-made changes in the environment, may add to or subtract considerably from the effect of carbon dioxide on climate.

S_5: Natural Climatic Change.

Natural processes could be warming or cooling the earth and compounding or counteracting the effects of human activities.

EXTERNAL FACTORS

X_1: Technological Breakthrough.

Breakthroughs in information, communication, and biological technologies increase productivity.

X_2: Strengthening of International Agencies and Institutions.

The cost of prevention, compensation, and adaptation might be reduced if cooperative international efforts are possible; for example, in technology transfer.

X_3: Weakening of International Agencies and Institutions.

The cost of compensation probably should be raised when the means to organize cooperative international efforts is lacking.

X_4: Media Speculation.

When models and historical analogues produce maps of the climate of the future, and press coverage leads to arguments over who will benefit and who will be harmed. Distributive issues are heightened. A mechanism is needed to determine whether you give to or receive mollifying transfer payments from other players.

X_5: Fusion.

There is a technological breakthrough which loosens the relationship between carbon emissions and energy production.

X_6: Limited War.

A portion of GNP or principle should be destroyed in a limited war. One (civil) or more (international) players participate.

X_7: International Monetary Systems in Crisis.

It is difficult to get bank loans to finance carbon imports. GNP growth rate is lower than expected.

X_8: Political Chaos in Carbon-Producing Areas.

If you are a carbon importer, you are forced to endure temporary cutbacks in carbon fuels usage. Higher costs of domestic supplies or other substitution reduce growth.

X_9: Natural Disaster.

There is a severe earthquake in your country.

X_{10}: Acid Rain.

If you are a heavy user of coal, you are probably also an acid rain producer. To reduce sulfate emissions, you try to reduce coal burning, but emission control makes you less energy-efficient, so CO_2 release remains unchanged. However, players who have not adopted a heavy coal strategy receive reparations from you.

X_{11}: Nuclear Disaster.

It is a cost for the period, and it also turns the public against nuclear energy, so nuclear prevention options become unavailable for the next few time periods.

X_{12}: Prolonged Unrest in Coal Mining Unions.

You unexpectedly have to import to meet domestic carbon demand. This results in increased costs for you for the period and a benefit for another player.

X_{13}: Evidence of Climatic Change.

There is dramatic evidence of human-induced change, and in the news disasters dominate positive events. Public pressure for preventive and compensatory measures increases, at no matter what the cost. Each player must pay, and the rate of investment in prevention increases in the next time period.

X_{14}: Drought in the Sahel.

There is another terrible drought in the poor and arid lands bordering the southern Sahara. This time the affected countries attribute the drought to human-induced climatic change brought about by heavy energy use in the rich countries. The richest player makes payment to the poorest player.

X_{15}: Foreign Exchange.

Lacking foreign exchange to buy carbon fuels, carbon importers are forced to use an alternative energy strategy in the next period.

X_{16}: Deep Earth Gas.

Natural gas emits less CO_2 per unit of energy than other carbon fuels, and it turns out that there is much more natural gas underground than traditional geological explanations have forecast.

X_{17}: Depression.

There is a decrease in economic activity, which can lead to reduced CO_2 emissions, but mostly players shift to cheaper, dirtier fuels. Reduce GNP growth for the period, and you are too poor to maintain preventive or adaptive measures—environmental protection is a luxury—reduce a prevention or adaptation factor, if you can.

X_{18}: Lifestyle Change.

Materialism is going out of fashion in the industrialized countries. Consumption patterns shift toward low energy services (music, video networks, mystic religions). The carbon/GNP ratio is decreased.

X_{19}: Global War.

Population, productivity, emissions reduced. Is anyone still concerned with the CO_2 issue?

NOTES

1. For a survey of the CO_2 issue, see W. Clark (ed.) (1982), Carbon Dioxide Review: 1982, New York: Oxford Univ. Press.

2. The carbon and climate gaming group was an informal research group that met together during the period March 1980 to September 1981 and included Jesse Ausubel, Ingolf Stahl, Jennifer Robinson, John Lathrop, and Karen Closek.

3. For a brief integrated summary of climate change to the year 2000, see L. Thompson, "Climate change and world grain production," pp. 100-123 in The Politics of Food, Chicago Council on Foreign Relations (1980).

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