# National Responses to Global Warming

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**Abstract.** An order-of-magnitude analysis is made of the present costs and the long-term benefits of national efforts to limit the impact of 'enhanced greenhouse' global warming. The analysis uses a simple numerical model of the interaction of six nations, each of which can take a range of preventative measures to limit their emission to the atmosphere of carbon dioxide, and each of which can take a range of measures to adapt to climate change. The preventative measures include conversion of coal burning power stations to nuclear or to gas-fired stations, improvement of transport efficiency, growth of new forests, and reduction in population growth. The model considers both the climate-sensitive economic sectors of each nation and the environmental sectors such as health, bio-diversity and environmental quality. Considering only the climate-sensitive *economic* sectors of the nations (agriculture, forestry, water resources and coastal infrastructure), the model suggests that measures taken purely to reduce greenhouse gas emission will not be cost effective. The main reason is the five to ten percent annual discount for the future normally associated with the economic items of human production. Measures to reduce emission in the 'no regrets' category (measures which are otherwise desirable such as improvement in transport efficiency) are exceptions. Inclusion of *environmental* sectors in the calculations ensures that the long-term benefit of preventative action usually outweighs the costs provided that the annual discount for the future associated with such sectors is of the order of 1% or less. Again considering only the economic sectors, active adaption by a nation seems always more cost effective (for that nation) than is a strategy of prevention. Conversion of solid-fuel power stations is a relatively costly strategy on a per person basis for Australia because of its low population and because of the large dependence of its industrial output on coal.

## 1. INTRODUCTION

There is a measure of agreement among scientists that the Earth may warm by a degree or two over the next century because of extra input to the atmosphere from human activity of carbon dioxide and other greenhouse gases. As a consequence the nations of the world are negotiating the Framework Convention on Climate Change (FCCC). The Convention is an attempt to limit the national emissions of greenhouse gases in order to slow or halt the change of climate which may follow as a consequence of the 'enhanced greenhouse effect'.

In principle the negotiation process should involve a quantitative analysis by each nation of the costs and benefits to itself of whatever is the set of actions proposed by the international community. In practice this is scarcely possible. Scientists cannot yet translate their general prediction of an overall warming of the Earth to predictions of the specific change of climate which might occur in any particular region. Economists cannot yet predict the likely impact on a region of a specific change of climate. Ecologists cannot yet predict the likely impact of a specific change of climate on the natural environment. There are as well the political difficulties which arise because the impact of climate change may be detrimental or beneficial to a country as a whole; because some sectors of its economy may gain and others lose; because in the global context some countries may gain and others lose; because the cost of a particular strategy for prevention of greenhouse gas emission will vary greatly from country to country; and because the cost and success of a prevention strategy in one country will generally depend on the prevention strategies of others.

All of which makes the point that decisions on how to implement the Convention (or indeed on whether to implement the Convention) must be based more on political judgement than on scientific considerations. The question each nation must ask is whether the potential cost of its own response to greenhouse warming is 'worth it' in terms of long-term benefit associated with a reduced impact of climate change well into the next century. Since the question and its answers are so much a matter of politics, it is not necessary to perform *overall* analyses which demand high numerical precision. The models which are used need be no more complex than is compatible with 'back-of-the-envelope' calculations and with the normal process of political decision making. Perhaps their most important characteristic is that they should be simple enough for the basic assumptions to be challenged and changed by the user. This is not to say that the simple internal relations of the overall model may not themselves be based on detailed and complex analysis. Such analysis may be necessary to yield even the most basic qualitative picture of the relation between one variable and another.

The present paper describes such an overall model. It is designed to assess only the national-scale costs and benefits of responses to greenhouse warming, and thereby ignores at least a few of the political difficulties associated with attempting to optimize too many variables. Its internal relations are generally no more than broad approximations to qualitative expectation. To the extent that conclusions are drawn from its behaviour, it is assumed that no result is significant at less than the order-of-magnitude level.

## 2.0 MODEL DESCRIPTION

### 2.1 Overall Structure.

The model derives originally from a workshop on climate impact response functions held at Coolfont in West Virginia in 1989 under the auspices of the Intergovernmental Panel on Climate Change (IPCC, 1989). Following the workshop a preliminary 'cost/benefit' model was developed under contract from the University Corporation for Atmospheric Research (UCAR, 1990). The present work is a development which includes, among other things, a specific attempt to handle both natural and forced adaption to climate change, and a specific (albeit essentially qualitative) attempt to handle the response of the environmental sectors of the various nations.

The model concerns six nations or regional groupings of nations (Australia, Brazil, the EEC, the USA and the region covered by the former Soviet Union) and their seven basic climate sensitive sectors of agriculture, forestry, water resources, coastal infrastructure, health, biodiversity and environmental quality. Each nation (the groupings are referred to as nations in the following) can take any degree of action involving either active *adaption* of its climate-sensitive sectors to climate change or active *prevention* of climate change by limiting its output of greenhouse gases. The possible preventative actions by each of the nations are as follows:

- conversion of coal burning (electricity generating) power stations to nuclear power stations;
- conversion of coal burning (electricity generating) power stations to gas-fired power stations;
- improvement of the efficiency of oil burning transport;
- growth of new forests to absorb atmospheric carbon dioxide ($CO_2$); and
- reduction of population growth rate.

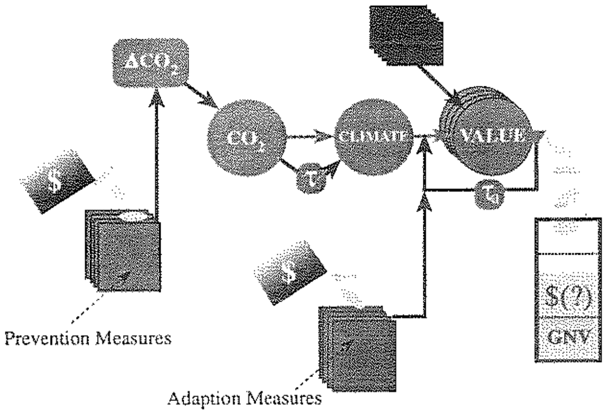


**Figure 1:** Cartoon of the role of changing CO2 (and hence climate) on the gross national value of a nation and the impact of preventative and adaptive measures.

Figure 1 presents the overall situation of an individual nation. The level of $CO_2$ in the atmosphere ($CO_2$ is the dominant greenhouse gas and is used here as a generic term for all anthropogenic greenhouse gases) determines the distribution of climate, and in turn the distribution of climate determines the value of each of the climate-sensitive sectors of the society. In the present model the value of each of the sectors is expressed as an annual figure more-or-less equivalent to a contribution to gross national product. This is reasonably acceptable for the purely economic sectors of society (agriculture, forestry, water resources and coastal infrastructure) but is much less so for the "environmental" sectors of health, biodiversity and environmental quality. The detail of the assignment of annual values is discussed shortly, but at this stage it is enough to recognize that the total annual value of the climate-sensitive sectors is represented in the diagram as a pot of dollars labelled Gross National Value (GNV) which, in the absence of climate change, is 'filled' to the level of the upper dotted line.

The extra annual input of $CO_2$ by humans ($\Delta CO_2$) leads to a change of climate determined among other things by the time constant of the earth-atmosphere system. The change of climate forces a change of sector value which may be either positive or negative, but is assumed to be negative in the diagram so that the overall effect can be shown as a loss in GNV (to the lower dotted line in the pot). Many of the sectors have a natural adaptive ability which, given time, tends to reduce the detrimental effect of climate change. Adaption is incorporated in the mathematics of the model by assignment of adaptive time constants to each of the relevant sectors. The values of the sectors, and particularly the values of the economic sectors, should depend to a great degree on the values of equivalent sectors in other nations because of competition and trade. The model has the facility to include functions representing interactions of trade between nations, but such interactions are not considered in the present analysis.

Figure 1 includes a pictorial presentation of the prevention and active adaption measures which might be taken by a nation. The prevention measures reduce $\Delta CO_2$ and its associated climate change. Their effectiveness is largely dependent on the prevention measures of other nations since they all make their impact via reduction of $CO_2$ in the common global atmosphere. The effectiveness of active *adaption* in preserving the sectoral values against climate change is more-or-less independent of the actions of other nations. The diagram makes the point that both types of measure will usually cost money, and the desirable outcome should be a reduction in the loss of GNV occasioned by the climate change.

The model is a numerical representation for all six nations of the relations indicated pictorially in Figure 1. A single trial of the model involves specifying the degree of the individual actions to be taken by each of the nations and how long it will take to implement them; calculation of the costs of the actions and, in the case of preventative actions, calculation of the associated reduction in production of $CO_2$; calculation of the degree of climate change both with and without the reduction in global production of CO2; calculation of the benefits of the actions in the form of increases(?) in sectoral values or in the form of reduction in the costs of necessary protection against climate change; and finally the calculation of the costs and benefits per person of each of the nations, where the costs and benefits are the sums of the annual costs and benefits over the full period of the operation of the model and onward into the indefinite future. The model performs its calculations on a year-by-year basis from the present (i.e. the year 2000) to the year 2100, and all the annually calculated costs and benefits are discounted for the future.

This matter of discount for the future is crucial. Without going into detail, discount for the future attempts to account for the normal decrease of perceived value of an item or perceived importance of an issue with 'distance' into the future. If there is no such discount then the summation of costs and benefits into the indefinite future leads to infinite values which make a nonsense of any analysis. The only alternative is to impose an arbitrary limit on the number of years over which the summations of the annual costs and benefits are performed. One might for example set a limit of 4 generations (about 100 years) on consideration of long-term benefit. In practice this is equivalent to sudden application of 100% discount for all years after the first hundred. This seems a far less acceptable assumption than the normal process of attributing a small but finite discount rate for each year onwards from the present. Therefore the discount rates in the model are applied year-by-year until the year 2100. The further summation to infinity is performed by an analytic formula which assumes continued discounting of costs and benefits whose undiscounted values remain the same as those reached in 2100.

The following sections are purely qualitative descriptions of the elements of the model. The quantitative input data and internal relations are described in Paltridge (1997).

### 2.2 Sector Values.

The climate-sensitive sectors of the nations are separated into three categories. First, there are the purely economic sectors - agriculture, forestry and water resources - where the annual value to each country is fairly easily definable in dollars in the terms of contribution to gross national product. Second, there are the coastal infrastructure and health sectors where it is assumed each nation must actively protect itself completely against the impact of climate change. In these two cases the benefits of preventative actions to limit $CO_2$ emission lie in the reduction of the annual costs of protection. Coastal infrastructure is another 'economic' sector in the sense that its value is fairly easy to define in dollars. Health is more akin to an environmental sector. Third, there are the environmental sectors of biodiversity and of environmental quality, where it is inevitable that the annual values have to be defined by almost purely qualitative criteria. It seems that the only practical way to assign a dollar value to a sector of this type is to consider the amount of money a national population might be prepared to pay to preserve it 'as is'. Such consideration must rely heavily on value judgements.

Thus for the agriculure, forestry and water resources sectors it is necessary to calculate future annual values (e.g. their annual contributions to gross national product) as functions of climate change and hence of time. The functions used here derive ultimately from the work of the Coolfont workshop. The calculations take into account natural adaption (for which time constants are specified as input data) or 'active' adaption (for which time constants are specified if adaptive action is to be taken by a nation).

For coastal infrastructure the cost of protection against sea-level rise is specified as a function of the amount of that rise which in turn is specified as a function of the degree of climate change. Both functions for each country used in the present work again derive from the Cooffont workshop. For the health sector it is assumed in the absence of hard data that the annual cost of protection against diseases which may arise in new areas as a consequence of climate change is directly proportional to the degree of the change. The proportionality factors are given in Paltridge (1997) and are more or less pure guesswork.

Attempts to quantify environmental values in terms of money normally involve an assessment of what society might be prepared to pay to preserve whatever aspect of the environment is being considered. It is far from certain that there will ever be a consensus on the matter. For the purposes of the present model it is assumed that the amount an individual is prepared to spend on maintaining an environmental sector (e.g. biodiversity or environmental quality) is an increasing function of his or her standard of living. It is assumed that, however high is that standard, the maximum a person might spend would be of the same order as the current expenditure on medical insurance by people in nations of high standard of living - perhaps a few percent of annual income. It is assumed that the values so defined will reduce in proportion to the expected degree of climate change. Finally it is asumed that there can be no adaption to the change.

The values of the sectors may vary with time because of changes in national population, gross national product and, in the case of the environmental sectors, the *expected* degree of climate change. A 5% per year discount for the future is applied to the values and costs associated with the economic sectors in all the calculations reported here. Unless otherwise stated, the equivalent annual discounts for the environmental sectors are set at 1%.

### 2.3 Prevention Actions

Each preventative action by a nation can be implemented to a choosable degree defined in the model as a fraction of some 'reference level' of action. For coal to nuclear or coal to gas conversion, the reference level is the maximum possible action corresponding to replacement of all current coal-fired electric power stations. For growth of forests the reference level is the planting of forests over all likely usable land in the particular nation. For improvement of transport efficiency, the reference level is a 10% improvement in efficiency (that is, a 10% reduction in the use of oil per unit of transport) by the year 2020. For population control the reference level of action is a reduction of growth rate to zero by the year 2050.

The model calculates for each action both the costs and the reduction in the national annual output of $CO_2$.

**Coal-to-Nuclear and Coal-to-Gas Conversion:** Both the capital replacement costs and on-going difference in operating costs are calculated in the context of national electricity generation. The replacement programme is spread uniformly over a choosable number of years from the present. The capital cost per year is reduced by the annual depreciation of the old equipment so that, for example, if the specified replacement time is greater than the depreciation time of the old equipment, the capital cost of the prevention action is zero. Discount for the future reduces both the capital and extra operating annual costs with time. The extra operating costs are adjusted each year in proportion to the gross national product of the nation. The assumption behind that adjustment is that energy use is roughly proportional to some such economic index of overall national production. Input data concern the reference-level capital costs, the reference-level extra operating costs, the chosen implementation percentages for a particular trial of the model, and the implementation and depreciation times.

Input data include the present national contributions from electricity production to the annual global emission of $CO_2$. The reduction in emission because of a preventative action is assumed to be proportional to the degree of implementation. In the case of coal to nuclear conversion, 100% conversion gives a 100% reduction in the $CO_2$ emission. In the case of coal to gas conversion, 100% conversion gives only a 50% reduction since combustion of gas still produces significant quantities of $CO_2$.

**Improvement of Transport Efficiency:** This effectively involves a reduction in oil consumption and is handled in much the same way as the coal to nuclear and coal to gas conversion. It is assumed that the improvement (and the cost of the improvement) is spread uniformly over the years to the specified year of completion. Normal depreciation and replacement of the present vehicles is taken into account. The on-going costs (which are actually gains since there is less fuel consumption with improved efficiency) are again assumed to be directly proportional to gross national product, so that generally the gains increase as the years progress. The reduction in national $CO_2$ emission is assumed to be proportional to the degree of implementation.

**Growth of Extra Forests:** In the context of the greenhouse problem, the growth of extra forests is an action which sequesters the carbon of atmospheric $CO_2$ into the wood of the trees. It is an action which absorbs $CO_2$ rather than reduces anthropogenic $CO_2$ emission. The present model assumes that there is no continuing cost associated with maintenance of a growing forest once it is established. The capital establishment costs are calculated according to an empirical formula suggested by Dr. Roger Sedjo of Resources for the Future (RFF) in Washington DC. The total cost is spread uniformly over the period of implementation, and the annual cost so derived is discounted and integrated as for other preventative actions. The effective reduction in $CO_2$ emission by virtue of the growth of new forest is calculated on the basis that about 2.9 gigatonnes/year of carbon is absorbed by the 465 million hectares of current world forest.

**Population Growth Reduction:** The relations concerning population in the model are simply arbitrary numerical expressions of the broad principle that, other things remaining the same, the rate of emission of greenhouse gases increases as the population increases. The model assumes that there is a continuing cost associated with population reduction because of a change in gross national product which in turn is a function of population and standard of living..

The reduction in $CO_2$ emission associated with population reduction is calculated by assuming the emission rate is directly proportional both to gross national product and to standard-of-living (defined as gross national product per person). The constant of proportionality is the current US emission rate (1.0 gigatonne/year) for its present population and present standard of living.

### 2.4 Adaption Actions

The model allows active adaption to some choosable degree for the climate sensitive sectors of agriculture, forestry, and water resources. The choice in each case is made by selecting the time scale of active adaption - that is, by selecting the desired time scale for restoration of annual productivity to its original value. The adaption is incorporated in the calculations of sector value by replacing the time constant of natural adaption with the chosen time constant of active adaption. Active adaption is not undertaken if the effect of climate change is beneficial to the sector. The cost of active adaption is assumed to be proportional to the amount required.

### 2.5 Climate Change

In order to calculate the national impact of a particular climate change, it is necessary in principle that the new climatic conditions be specified in considerable geographic detail. Vast numerical climate models are being developed for the purpose. Given the new climatic conditions, and again in principle, it is then necessary to model the actual impact of the changes at a compatible level of detail. The two sorts of model, no matter how detailed, can be used to define two relations. The first is a relation between increase in atmospheric $CO_2$ and some single measure of the climate change of the nation or of the globe. The second is a relation between that single measure of climate change and the change in overall value of the national sector.

The present model assumes the existence of such simple relations, and envisages the single measure of climate change to be the change in average temperature of the Earth. That measure is numerically equal to the change in average temperature (in degrees Celsius) from pre-industrial times. The model assumes a linear relation between the global rate of anthropogenic emission of $CO_2$ and the actual atmospheric concentration of $CO_2$, and in turn that the change in average temperature is proportional (but delayed by a number of years equivalent to the time constant of the system) to the $CO_2$ concentration.

## 3. RESULTS AND DISCUSSION

It is perhaps going too far to say that the functions defining the sector values in terms of the degree of climate change are directly related to those from the Coolfont workshop. The absolute magnitude of the functions are based on the results of the workshop, but for the present illustrative purposes the sign of the functions has been reversed where necessary to ensure that the impact of the climate change is always detrimental. (The Coolfont results suggest that climate change may be beneficial to some of the national sectors). This deliberate forcing of detrimental impact of climate change is designed to ensure an overestimate rather than an underestimate of the long-term benefits of preventative and

**Table 1:** Total cost per person ($US) of the individual 'standard' preventative actions by each nation. 'Total cost' is the sum of the annual costs (discounted for the future) into the indefinite future.

| | Reduce Population Gr. | Coal to Nuclear Power | Growth of Extra Forest | Improve Effic. Transport | Coal to Gas Power | TOTAL |
|---|---|---|---|---|---|---|
| USA | 1407 | 2590 | 110 | -2124 | 1919 | 3902 |
| FORM SOV U | 192 | 1725 | 200 | -877 | 1277 | 2517 |
| AUSTRALIA | 557 | 6971 | 166 | -988 | 5161 | 11867 |
| CHINA | -44 | 528 | 21 | -51 | 391 | 843 |
| BRAZIL | 0 | 37 | 161 | -168 | 24 | 53 |
| EEC | 587 | 1152 | 21 | -867 | 854 | 1746 |

adaptive actions.

In the following discussion, the 'standard set of actions' by a nation refers to a complete set of the five possible preventative actions performed to degrees defined as follows:

(1) Coal to Nuclear Power: 50% conversion of all stations by the year 2020.
(2) Coal to Gas Power: 20% conversion of all stations by the year 2020.
(3) Forest Growth: Planting of 20% of maximum usable area by year 2020.
(4) Improve Oil Consumption: 20% improvement in transport efficiency by the year 2020.
(5) Reduce Population Growth: To 0% rate of growth by the year 2050.

There is no particular reason for choosing these numbers other than that they seem achievable. The following discussion is concerned mostly with relative costs and benefits, so that absolute degrees of action are not greatly significant.

The model-calculated costs costs per person, for each of the five standard actions and for each nation are given in Table 1. Note again that the costs are total costs (both capital and operating) summed over all years into the future, and are discounted for the future at an annual rate of 5%.

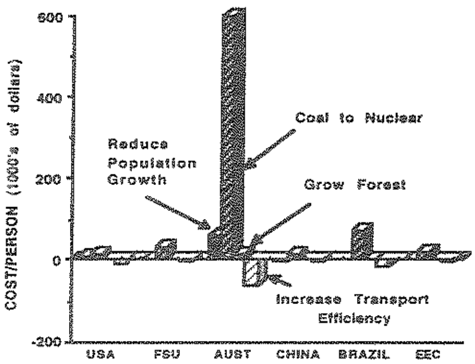


**Figure 2:** Relative effectivenessof money spent (per person) on preventative actions by each of the nations.

It is not surprising that improvement in transport efficiency should involve a gain rather than a cost for all the nations. It is not so obvious that the growth of forests should be such a relatively cheap option in the more developed countries. Forest growth is also a relatively effective action. Referring to Figure 2, which gives a measure of the cost effectiveness of the various preventative actions for each nation, forest growth requires far less expenditure per person to achieve a particular reduction in carbon emission than does conversion from coal to nuclear power. However the growth of forests is a 'one off' option. Once fully grown, forests can sequester no more carbon dioxide, so that the effectiveness of the action decreases to zero at some time in the future when the trees are old. The effectiveness of coal to gas conversion is not shown on the figure, but it is at least twice as expensive as the nuclear option since the reduction of $CO_2$ is so much less. Still referring to Figure 2, the apparently high cost per person in Australia for a given reduction in $CO_2$ emission is the natural consequence of its low population.

Figure 3 presents histograms of benefit-to-cost ratios calculated for each of the nations if they perform the standard set of preventative actions. The particular ratios in the figure concern only the long-term benefit to the economic sectors of the nations - that is, to agriculture, forestry, water resources and coastal infrastructure. The ratios are shown both for the case when the standard set of actions is taken by each nation alone, and when it is taken by all nations together. As is to be expected, the benefits are much greater when all countries contribute to the effort. The 'go-it-alone' option is particularly ineffective for a country of low population such as Australia.

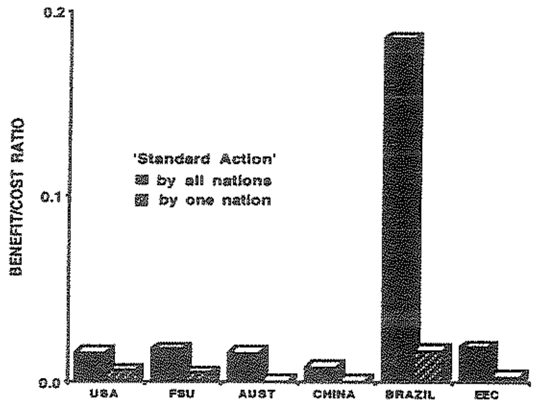


**Figure 3:** Histogram illustrating the benefit to cost ratio if all nations perform the standard set of preventative actions, and if nations 'go it alone'.

The major lesson from Figure 3 is that, even allowing for order-of-magnitude errors in the estimation of prevention costs and of sector values, the benefits to the economic sectors do not outweigh the costs of the actions. There are two reasons. First, the contribution of the climate-sensitive economic sectors to the national economies is generally less (in the more diverse and developed economies at least) than is the contribution of the energy-based sectors on which the preventative actions operate. There can be an element of 'spending a lot to gain a little' when a nation actively modifies its energy infrastructure on the sole grounds of limiting greenhouse warming. Second, and far more important, is the role of discount for the future. The preventative actions are taken now while the benefits of the actions are derived in the distant future. With an annual discount rate of the order of 5%, the 'distant future' need only be a few decades to ensure that the long-term benefit (or at least the monetary measure of long-term benefit) is much less than any present day cost of prevention.

Figure 4 also presents benefit/cost ratios for the standard set of preventative actons, but in this case the benefits to the environmental sectors of health, biodiversity and environmental quality have been included in the calculations. The histograms indicate the effect of lowering the discount rate on the environmental sectors from 5% to 3% and to 1%. The monetary measure of long-term benefit increases exponentially as the discount rate is lowered, so that at rates of the order of 1% the benefit-to-cost ratio is signifcantly greater than 1.0 for most of the nations. 'Significantly greater' in this case means greater by an order

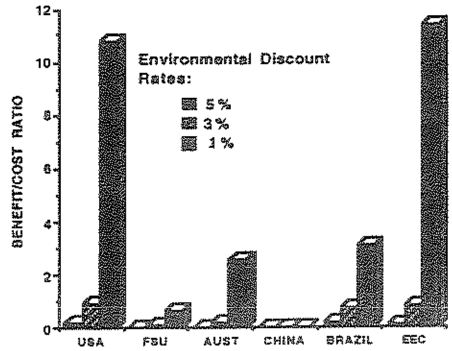


**Figure 4:** Benefit to cost ratios when all nations perform the standard set of prevention actions. Benefits include environmental sectors, which have been discounted for the future at 5, 3 and 1% per annum.

of magnitude, so that the errors in assignment of value to an environmental sector become fairly irrelevant. The relatively small benefit-to-cost ratio for China derives from the assumption in the model that the dollar value put on the environment by a nation is proportional to its average standard of living.

Figure 5 concerns the costs to the various nations of the four preventative actions which involve a positive expenditure. (The 'no regrets' action of improving transport efficiency is not included). The costs are those required such that each action would produce a 5% reduction in the current total emission by the nation. Thus the total height of each bar in the histogram is the cost of all four actions which together would reduce the national output by 20%. The most obvious point is that the cost to Australia of either form of conversion from coal-fired power stations is about twice that of other nations on a per person basis. The reason is because of that nations relatively low population, and the relatively high dependence of its industrial production on coal. The histogram makes the point again that growth of extra forest is a relatively cheap option, as is (if the assumptions of the model are to be believed) the reduction in population growth.

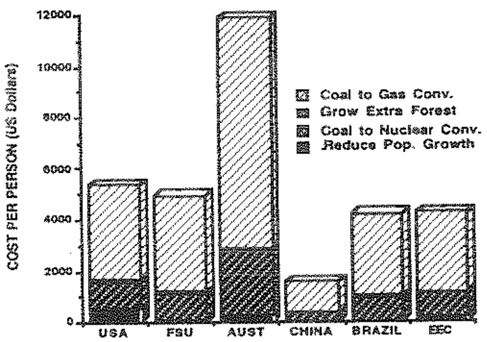


**Figure 5:** Costs of 5% reduction in current output of $CO_2$ by nation and by action.

Referring to active adaption (and again only with regard to the purely economic sectors of the nations) the calculations of the model return the maximum reasonable cost of adaption rather than the likely cost. The actual figures are not presented in this paper, but the general result is that active adaption is far more cost effective for an individual country (by two orders of magnitude) than is a contribution to reduction of the overall global emission of $CO_2$.

## 4. CONCLUSION

The present analysis is a more-or-less straight forward assembly of the sort of basic relations which will ultimately be needed if a realistic cost-benefit analysis is to be done with regard to greenhouse warming mitigation. Where quantitative relations are not available, the model simply uses convenient numerical representations of qualitative ideas about the costs and benefits of the various possible actions and their relation to climate change. This is particularly true with regard to the 'environmental' sectors of the nations, to which there is as yet no accepted method of assigning a value in dollars. Perhaps the most significant point about the present work is that it emphasizes again the fundamental stumbling block to cost-benefit analyses on the broad national scale - namely, the necessity to define the 'value' of all sectors of society in the same units.

The set of preventative actions incorporated in the present model is by no means an exhaustive list. There are many possibilities ranging from actions to limit the emission of other greenhouse gases (i.e. other than $CO_2$) to exotic adaptive measures such as 'draining of the oceans' into areas of land which are below current sea-level. However the set in the model covers perhaps all the large-scale possibilities. Only one of them (improvement of transport efficiency) falls definitely in the category of 'no regrets' - that is, it is an action which would be anyway worth taking for reasons other than limition of the emission of greenhouse gases. It is possible that the growth of extra forests might be beneficial for other reasons. It is also possible that such growth might not be as effective in reducing greenhouse warming as is calculated here, since extra forests have the effect of darkening the planet and raising its temperature because of extra absorption of solar radiation.

The present model deals only with six nations of the world. These six account for perhaps half of the global anthropogenic $CO_2$ emission, so that the calculated benefit-cost ratios might improve by a factor of two if all nations were considered.

## 5. REFERENCES


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