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Global Warming and Climate Policies

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Abstract
The paper starts reviewing some basics of the climate science and economics of the greeenhouse effect. It stresses the nature and extent of uncertainty on both sides as well as the political background of present climate policies. It then comes to an assesment of some of the main debates surrounding climate policies. When to act ? How to act ? two question that lead to confront the the promises of research and the merit of early abatments. The question of the urgency and intensity of action calls for some cost-benefit analysis of the kind presented in the Stern report, which is critically examined. The last section is concerned with the difficult question of designing the institutions of climate policies, and particularly with the key issue of the involvement of developing countries.

Keywords
Climate policies, Kyoto protocol, emissions and development, quotas, markets for permits, tax border adjustments, sectoral agreements

Global Warming and Climate Policies

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Introduction[1].

Although it may seem strange for an economist to initiate a series of 'Max Weber' lectures, I will not apologize, but I will start with a quotation from a social scientist. Marcel Mauss, who was indeed influenced by great predecessors, Emile Durkheim and also I guess, Max Weber. In Mauss's terminology, global warming may be viewed as "un fait social total". This phrase stresses the fact that global warming is a multi-disciplinary subject, not a stone in the field of economists. It concerns philosophers, and I will be quoting two of them, Hans Jonas and Jean Pierre Dupuy, who have written on the problem. It concerns, and has concerned, historians, for example my colleague Leroy-Ladurie has written an interesting book on the climate of France over the last millennium which is very relevant to some aspects of global warming. It is also an issue that should naturally interest political scientists as I will show later. And I might continue the list further.

Let me first say a few words on my own expertise and knowledge of global warming, which, I am afraid, reflect the approach of an economist. I came to the problem through government consulting when in 2002 I was asked to write a report for the French "Conseil d'Analyse Economique", a group of economists advising the Prime Minister. This report on global warming and Kyoto led to a book, "Kyoto et l'économie de l'effet de serre" (2003)[2], part of which has been translated into English. A subsequent publication for a general audience was published in Spanish with the title "Nos llevara a la ruina combatir el efecto invernadero?" and in French with the more fancy title "Combattre l'effet de serre nous mettra-t-il sur la paille?"[3] Being mainly, but not only, a theorist, I have also taken an interest in the subject in that vein. I wrote on the question

[1] This a condensed transcript of the conference. I thank Paul Seitz for his patience in typing a first transcript.
[2] La documentation française.
[3] Le Pommier, Paris, 2003

of discount rates in a 2004 scientific paper, "Calcul économique et Développement durable" (La Revue Economique), and a forthcoming paper on the design of climate policies will be included in a book, edited by Henry Tulkens (from the CORE at Louvain) and myself, which is due to be published by the MIT Press next year.

Global warming is a broad subject. In this talk I will present a broad overview, which means that I will cover all aspects of the issue, although necessarily rather superficially - a reasonable choice I hope. Basically I will address three subjects. The first part of the talk will consist of a reminder of the Greenhouse Effect, which is necessary for an understanding of what follows. The second part of my lecture is called debates and controversies, and looks at these questions: Is there still a scientific controversy? To act or not to act? Precaution or cost-benefit analysis? Which discount rate? Finally, the third part will be concerned with the governance and design of climate policy, the Kyoto agreement, and development.

1- The Greenhouse Effect, facts, responsibility and prospects.

First of all comes a reminder of the Greenhouse Effect. The basic fact is that there are some gases in the atmosphere called Greenhouse Gases, which trap light and heat. As Figure 1 shows, the atmosphere receives solar radiation and emits infrared (IR) radiation, creating an equilibrium between emission and reception which governs the temperature of the atmosphere. This is not a wholly negative phenomenon: if there were no greenhouse gases in the atmosphere the average temperature on earth would be -18°C and so we would probably not be here. Without going into great detail, the main Greenhouse gas is carbon dioxide (CO_2) and another which should be mentioned is methane. Our first rough understanding of the Greenhouse phenomenon seems to date back to 1826, when Joseph Fourier argued that the temperature on earth is governed by the balance between solar radiation entering and IR radiation exiting. That is the basic physics. (Figure 1)

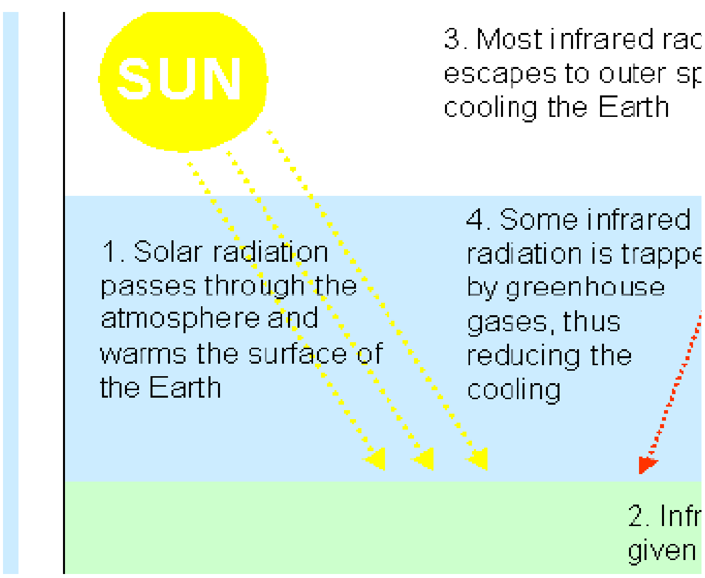

Figure 1

What has happened since the beginning of the Industrial Revolution in the early 18th century is that there has been a considerable increase in the concentration of Greenhouse gases in the atmosphere, and in particular in the concentration of CO2. This increase is anthropogenic, meaning that man is responsible, and follows from the intensive use of fossil fuels (essentially oil, coal and gas) since the beginning of the industrial revolution. The fact that the increase in the concentration of CO2 would be a problem for the future climate was stressed at the end of the 19th century, in 1896, by a winner of the Nobel Prize for physics Arrhenius. Later, in 2007, came a Nobel Peace Prize.

In a sense, the atmosphere is like a reservoir. When CO2 is added to it, some remains. Limiting ourselves to CO2, every year the world emits 6 billion tonnes of carbon into the atmosphere and about 4 billion remain in the atmosphere while 2 billion are captured by the ocean and by biomass. The exchanges are complex, but basically a large part remains. The concentration of Greenhouse gases has increased, and is going to increase spectacularly, as the following statistics illustrate. The concentration of CO2 at the beginning of the 19th century was 270 parts per million in volume (ppmv), which means that 0.27/1000 of the volume of the air was occupied by CO2. At present the concentration is 360, which represents a huge increase, and in 2100 it might be, depending on many factors which will be mentioned later, 450, 550, 750 or more. It should be noted that there are two different measures of concentration - concentration of CO2 and concentration of Greenhouse gases in equivalent CO2 – and so numerical comparisons should be made with care.

As an illustration of this, Figure 2 shows the evolution of the concentration of CO2. This evolution looks exponential in the recent past. The same is true for other gases such as NO and methane. This is clearly a stock phenomenon, following from accumulation. Furthermore, it has weak reversibility because CO2 remains in the atmosphere for a very long time.

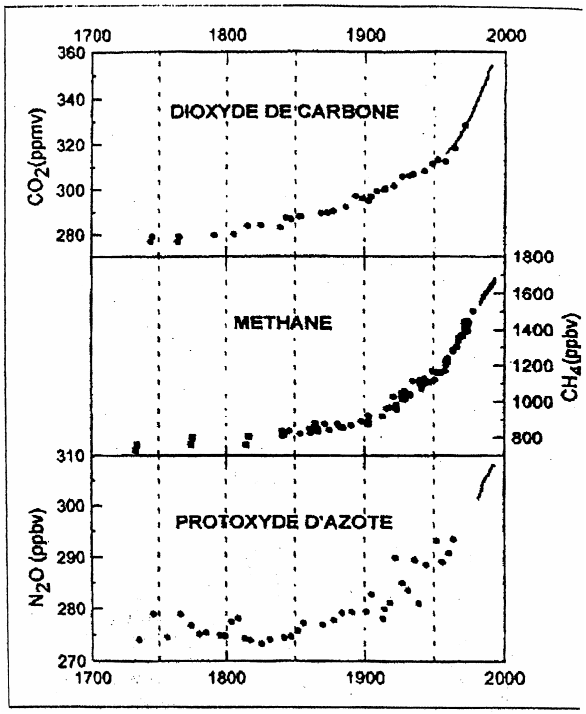

Figure 2

Figure 3 gives some worrying extrapolations of future CO2 concentration. It shows the situation at the beginning of the industrial era, at present, and three possibilities for 2100:

- 450 ppmv, which would be the result of a very successful strong climate policy;
- 550 ppmv, double CO2 concentration compared to pre-industrial time;
- 800 ppmv, which would result from "business as usual": doing nothing and not seriously implementing climate policies.

The last column extrapolates a catastrophe scenario in which all the carbon accessible on earth has been put into the atmosphere.

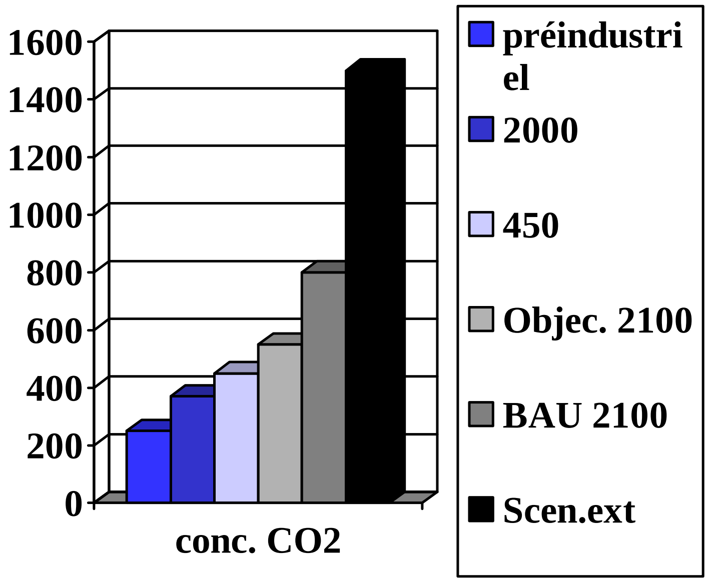

Figure 3

This difference essentially depends on differences in emission levels. There is still some uncertainty about the relationship between concentration and emission, but it has to a large extent been resolved. Fifteen years ago the part that would be captured by the ocean and by biomass was more uncertain but nowadays scientists generally agree, at least for the short run.

Turning to the connection between concentration and temperature, Figure 4 shows the relationship between the average temperature on earth and the concentration of carbon dioxide. In particular, since 1990 there has been a significant increase in temperature. The graph makes a connection between CO2 concentration and temperature seem quite probable.

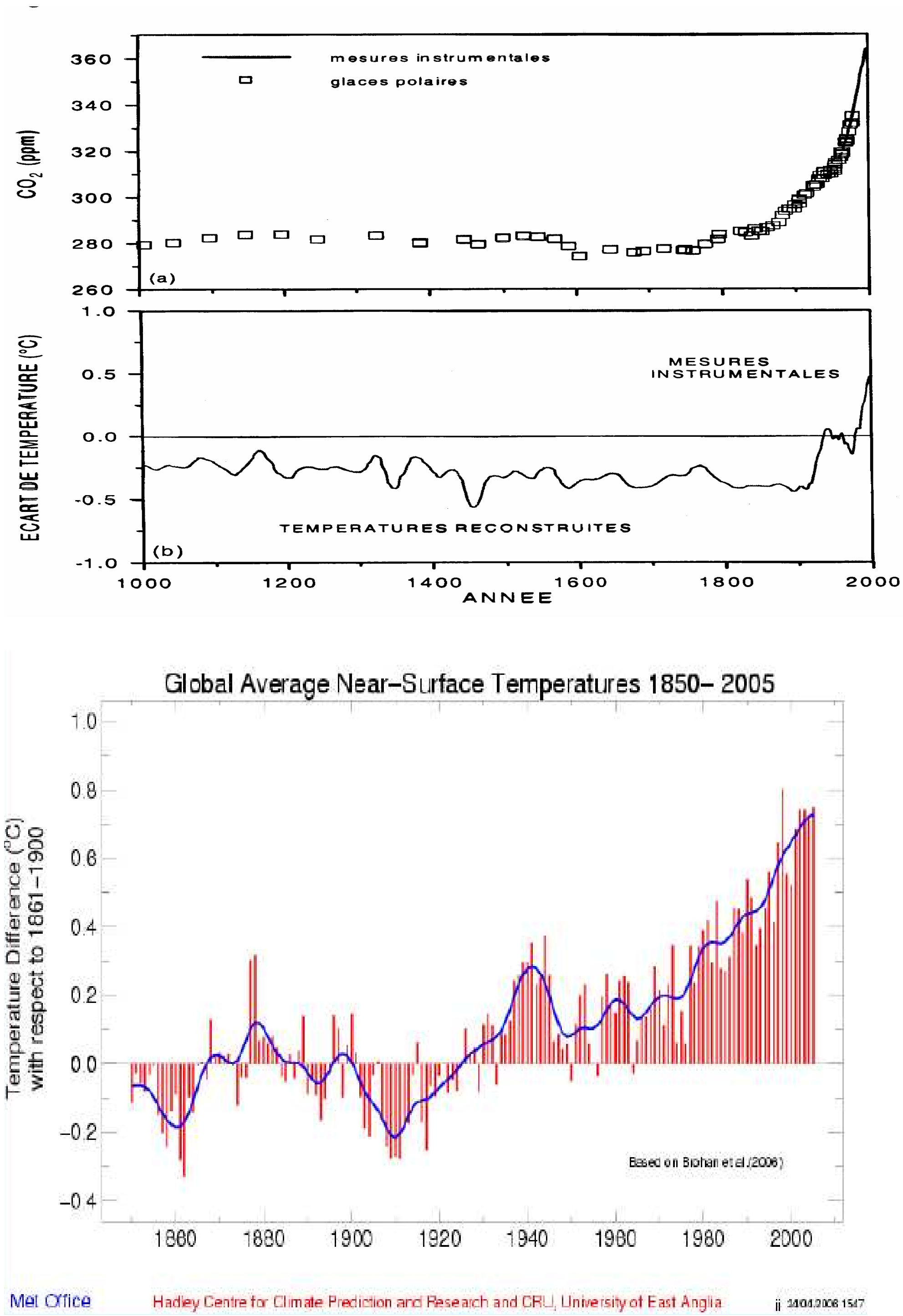
mesures instrumentales
glaces polaires
CO_2 (ppm)
(a)
ECART DE TEMPERATURE (°C)
MESURES INSTRUMENTALES
TEMPERATURES RECONSTRUITES
(b)
ANNEE
Global Average Near-Surface Temperatures 1850– 2005
Temperature Difference (°C) with respect to 1861–1900
Based on Brohan et al.(2006)
Met Office
Hadley Centre for Climate Prediction and Research and CRU, University of East Anglia

Figure 4

Figure 5 shows how the connection takes place and the effect on the increase in temperature.

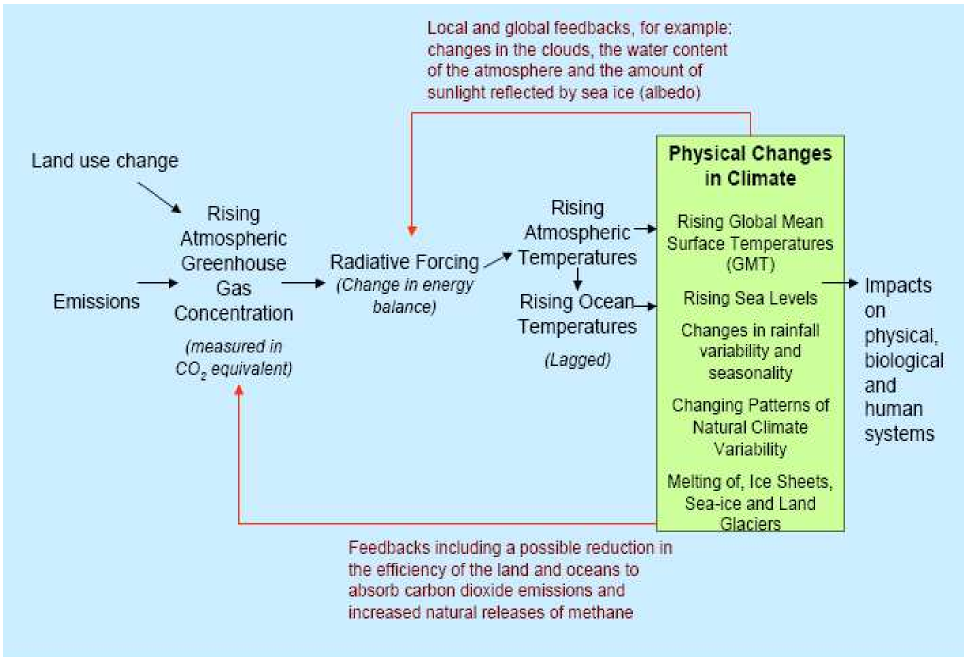

Figure 5 The link between greenhouse gases and climate change

Moving on to climate change predictions, these depend on the concentration predictions and there are a number of uncertainties. In the background is the uncertainty about emissions which has already been mentioned, depending on factors such as economic activity and policy. As argued before, there is some slight uncertainty about the connection between emissions and concentration; although it is slight now, it may increase because of the possibility that after a while the ocean will no longer absorb carbon dioxide so well and might even release it. So, in the short term, there is not much uncertainty about the emission-concentration connection; the largest uncertainty regards the effect on climate.

Concerning the climate effect, it should be stressed that there is no doubt about the basic physics or chemistry. This basic knowledge triggered the early prediction by Arrhenius, who argued that if we double the concentration of CO2, which is within the range of plausible prospects for 2100, then the average temperature on earth will increase by four degrees. This is compatible with what is now obtained from the many climate models that have been developed. Indeed, climatologists have developed very large models using powerful computers, and in spite of the problems mentioned above, these models made predictions 15 years ago that have turned out to be rather well-validated by the facts. We are thus able to be much more confident about their predictions now than we were 15 years ago.

What the models provide is not a deterministic picture of the future but a probabilistic assessment with a significant variance in average temperatures and still more in local effects. This is illustrated by Figure 6, which shows multi-model averages of assessed surface warming. **E**ach of the lines shows a possible evolution of average temperature over the 21st century depending on emissions, the level of economic activity, and on the success of climate policy. The first line is interesting because it demonstrates that even if we were able to maintain the concentration of CO2 at the present level, then the temperature would still increase over the century. This is one aspect of the irreversibility which was stressed above.

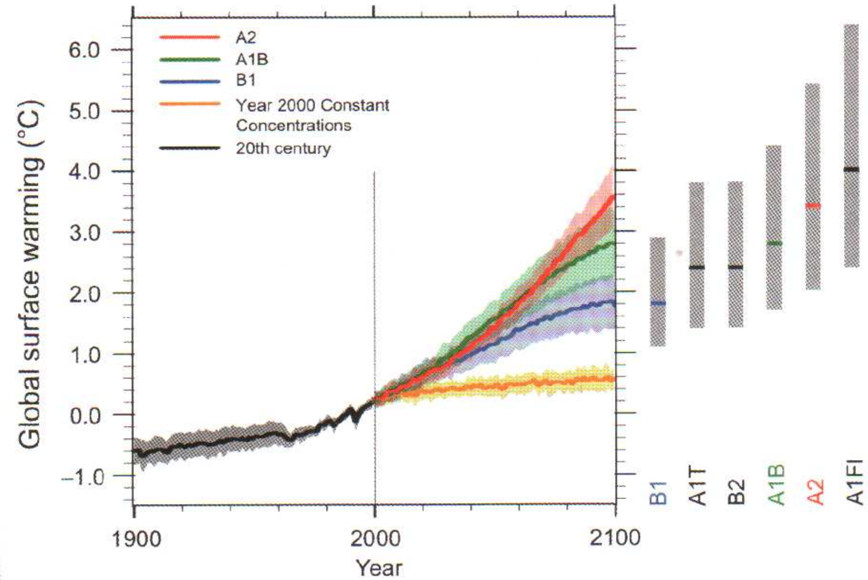

Figure 6 Multi-model Averages and Assessed Ranges for Surface Warming

There are a number of other possible scenarios, and the range of variation between them is significant. Figure 7 gives a better idea of this variation. It shows a probabilistic assessment of the effect of reaching certain concentrations in 2100 with curves representing the density of repartition of temperatures. Each of the curves corresponds to one scenario and they demonstrate the extent of the uncertainty. For example, according to the IPCC, with 550ppmv CO2 equivalent the range of the increase in temperature would be between 1.5 and 4.4 degrees; according to another model it will be between 2.4 and 5.3, and taking into account all the models, there is a still higher variance.

Stabilisation level (ppm CO_2 equivalent)	Temperature increase at equilibrium relative to pre-industrial (°C)		
	IPCC TAR 2001 (Wigley and Raper)	Hadley Centre Ensemble	Eleven Studies
400	0.8 – 2.4	1.3 – 2.8	0.6 – 4.9
450	1.0 – 3.1	1.7 – 3.7	0.8 – 6.4
500	1.3 – 3.8	2.0 – 4.5	1.0 – 7.9
550	1.5 – 4.4	2.4 – 5.3	1.2 – 9.1
650	1.8 – 5.5	2.9 – 6.6	1.5 – 11.4
750	2.2 – 6.4	3.4 – 7.7	1.7 – 13.3
1000	2.8 – 8.3	4.4 – 9.9	2.2 – 17.1

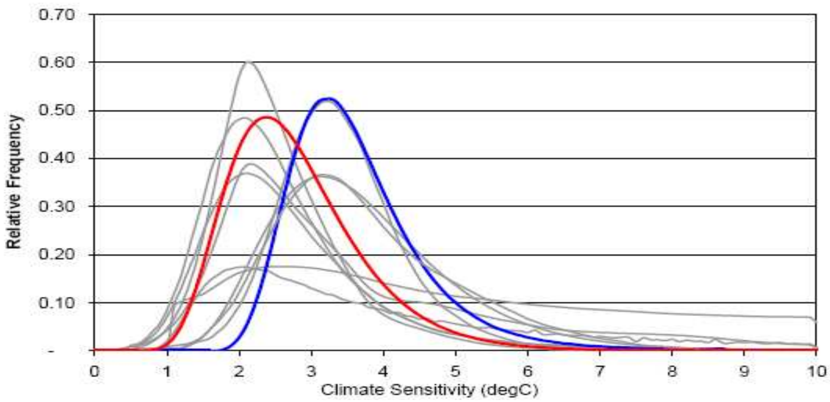

Figure 7

It should be borne in mind that an increase of 5 degrees in average temperature on earth is a huge change. At the end of the last ice age the average temperature on earth was 5 degrees below the present temperature, and most of France was covered by ice. Although I do not know how Florence or Barcelona were affected, this made a huge difference compared to our present climate. Figure 8 gives some simulations of the local effects, which are obviously more difficult to predict from the climate models. It shows the likely local effects in the case that the temperature increases by more than four degrees.

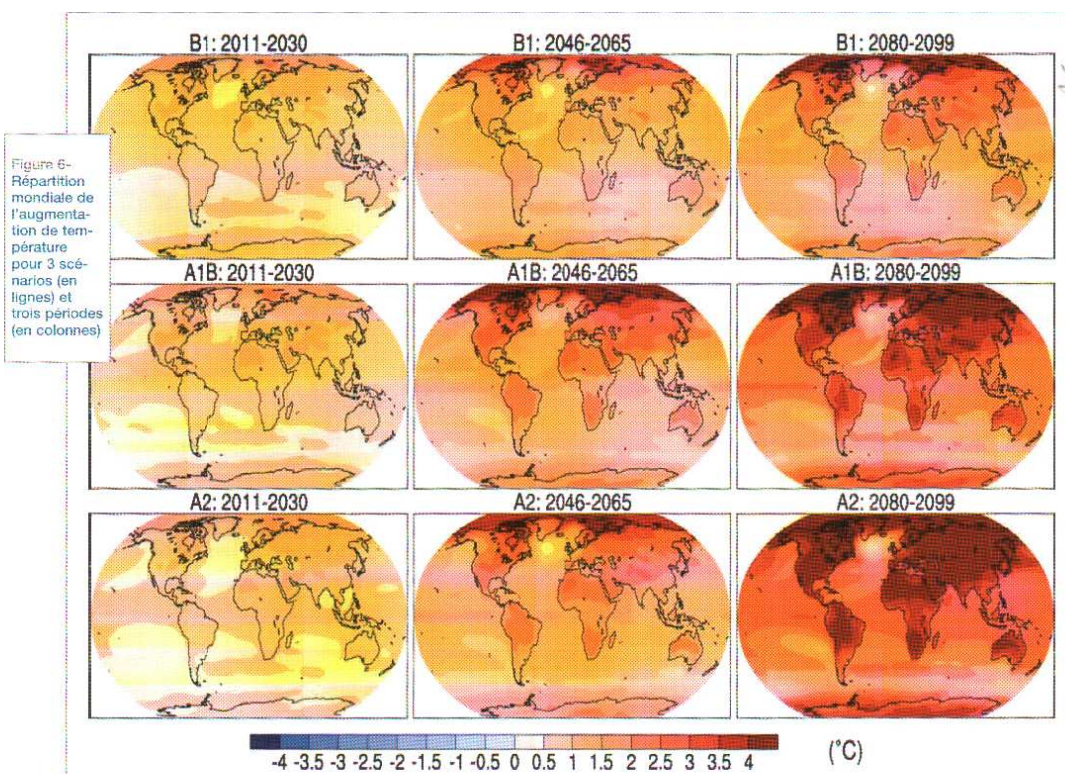

Figure 8

Next, let us turn to the sectoral origins of CO2. As Figure 9 shows (although there is some variation between industrialised countries, and France, for example, is somewhat different), basically there are four sources of emissions: energy production, transportation, industry, and agriculture plus housing. The four sectors contribute almost equally, with energy generally dominating: roughly speaking energy production accounts for between 20 to 32 percent of the total volume.

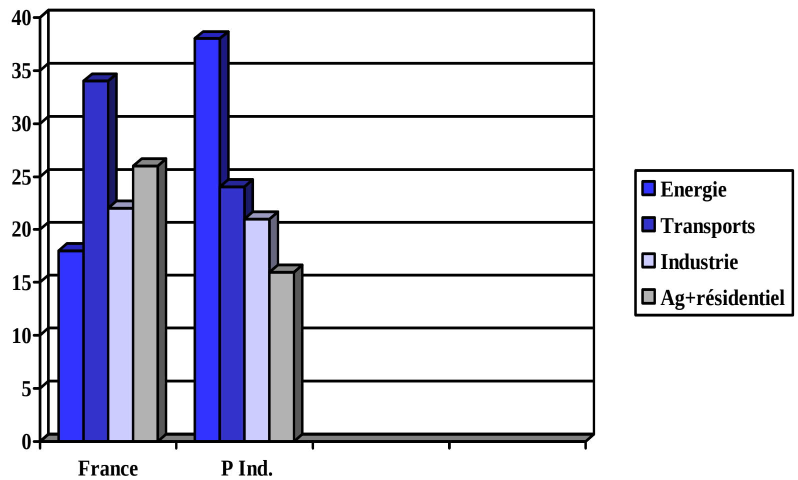

Figure 9

Some international comparisons are interesting. For instance, the total amount of carbon sent into the atmosphere each year is approximately 7 gigatons, which means roughly one ton for each human being living on the earth, but there is much variation between countries. For example, an American citizen emits 6 tons, yet an Indian citizen only produces a little more than 300 kg. The figure for Europe is 2.3 tons. As Figure 10 shows, emissions per capita are naturally closely related to development.

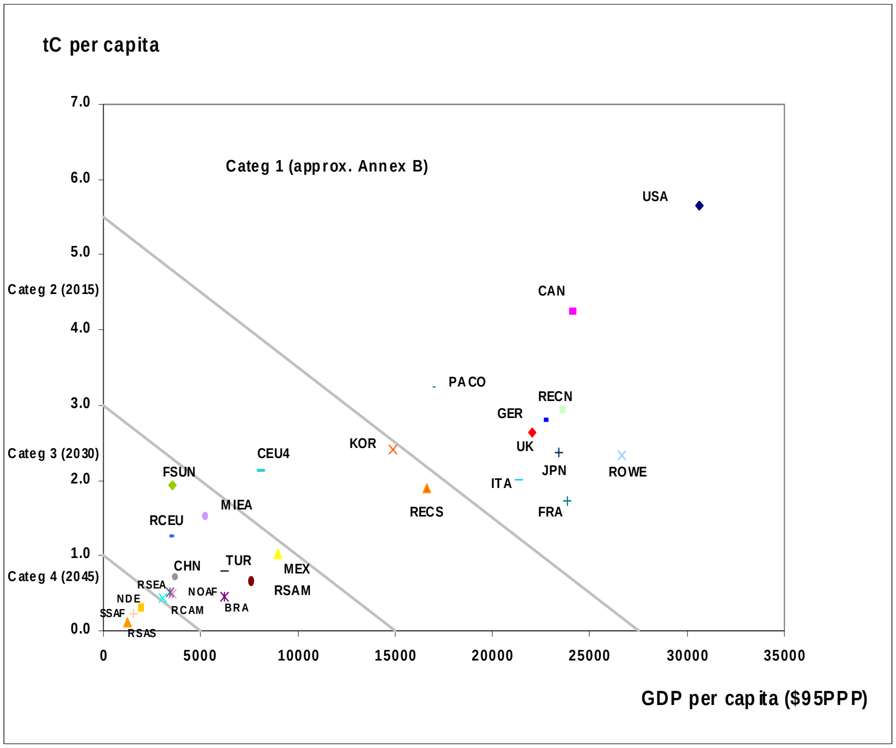

Figure 10

Moving on to the possible solutions to the problem, one possibility would be returning to pre-industrial life, in which case we should not emit more per capita than our ancestors, although in total volume we would still emit more because there are many more of us. Nevertheless this solution would represent a large decrease. In this case we would probably not even be allowed to use bicycles because they are made of steel, and steel production generates a lot of CO2.

Clearly, in the short term an increase in the use of renewable energy, and for example the European Union objective of reaching 20% of energy use from renewable sources (windmills, solar energy, biofuels, geothermal energy, hydraulics, tidal energy and so on) makes sense, but is far from exhausting the problem. In an article in Scientific American, Princeton professor Robert Socolow, a specialist in the comparison of technologies for combating the Greenhouse Effect, outlines seven of the fifteen 'wedges' which he has identified as capable, in combination, of stabilising 2050 emissions at the present level - in principle an under-ambitious target, but already very difficult (Figure 11).

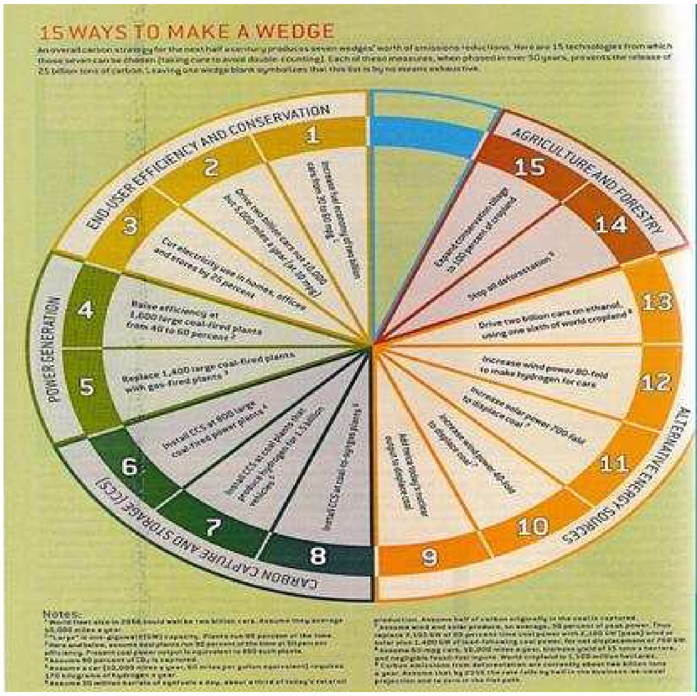

Figure 11

The first wedge involves the improvement of energy efficiency; the second requires the creation of 2 million windmills (which is a very large number); the third is to partly de-carbonate electricity production with carbon storage - carbon capture and storage; the fourth is the development of nuclear energy, with some uncertainty on feasibility depending on public sentiment; and the last three relate to methane, transportation (using bio fuels), and stopping deforestation in many countries.

In the long term, after 2050 new technology will be needed to decrease emission levels as much as is necessary. New technologies which are already on the agenda include using hydrogen for transportation (the question is how to produce it in a carbon-free way), drastic progress in photovoltaic energy production, and new means of generating nuclear power, such as ITER.

2- Debates and controversies.

Everything said so far is, of course, a potential source of debate and controversy (nuclear energy is just one example) but these debates are beyond the scope of this paper, which will focus on three questions:
- What about science? Are there still scientific controversies?
- When and how to act?
- How to discount the future?

First: What about science? Is there a scientific controversy? It has already been stressed that although there is no doubt about the basic science, there are large uncertainties regarding emission levels. Concerning the assessment of climate models, there has been some debate, for example on the role of clouds. This is one instance of a source of the significant variability of the results presented above.

Scientific uncertainty also concerns problems that are not at the heart of present modelling because they are likely to appear further in the future, such as the possible occurrence of what may be called surprises, taking place mostly in the long term. One surprise might be the stopping of the thermoaline circulation in the North Atlantic Ocean. Briefly, this would mean the end of the Gulf Stream, so that the prospect for Europe would be entirely different to what we might imagine: instead of becoming like Seville, Paris would have the climate of some Baltic town (an interesting dilemma). Indeed, beyond 2050 or 2100 we do observe that the thermoaline circulation starts to weaken. Another surprise could come from the release of large quantities of methane from permafrost as it thaws.

Given this, and taking into account the uncertainty, there is nevertheless a broad consensus among scientists on the anthropogenic origin of the present evolution of temperature. The increase observed in the last 15 years very likely comes from the accumulation of Greenhouse gases, in spite of the other influences on earth's temperature. The latest IPCC report gave this a probability greater than 0.9. Although some scientists consider 0.9 too high, it seems to be the only real controversy. This was not the case three years ago when I started working on the subject: there were still some reasonable scientists who strongly opposed the (newly) dominant view. Just recently at an executive directors meeting at the World Bank in Washington on the subject, a representative from an oil country objected that there was still scientific disagreement. It was claimed that some oil companies had proposed large monetary awards to a scientist who would demonstrate that the now orthodox climatologist's view is incorrect. (Disagreeing with the now orthodox view could be a very profitable activity!)

The next controversy concerns the question "When to act?" This, of course assumes that some action is necessary. Although almost everybody agrees to some extent, we will return to that question later.

The choice of the Kyoto protocol was clearly to act now, to engage now in what is called mitigation, the reduction of carbon emissions. The point was controversial. In particular, when President Bush came to power the last American administration argued forcefully that the best solution was to wait for solutions to come from research: the problem would not be solved by reduction, but by research, so we should do research. In fact the US has engaged in some research, which is, incidentally, a good idea.

By way of parenthesis, timing and intensity of action cannot be independent and have to be determined through a full cost-benefit analysis. This involves going into complex arguments, for example the option values arguments known to economists. However, the answer to the question "Should we engage in research only, rather than abatement?" is simpler, because it relies on simple, robust insights which I would like to stress here.

First, a strong argument for acting now is the lifetime of energy investment. A coal power plant, like those nowadays being built in China, will last for, let us say, 40 years.

Given that China is likely to build a very large number of such power plants in the next 15 years, there is a strong argument for trying to act quickly.

A second robust insight is the fact that mitigation or reduction on the one hand and research on the other hand are not alternatives, but really complements. The fact that Kyoto exists, incomplete and unsatisfactory as it is, has generated a lot of research in the world, because it has made it clear that there is some commitment among the international community, and this commitment argument is very important.

A question which is more difficult to resolve concerns the intensity and timing of action: how much and when? It is tempting to deduce the answer from the precautionary principle. This states that "the absence of certainty at a given state of scientific and technological knowledge should not delay effective and proportionate response to avoid serious and irreversible damage to the environment". This clearly fits the present problem: there is an absence of certainty, there is a risk of serious and irreversible damage to the environment, so we should take effective and proportionate action. The question is what are the effective and proportionate actions? Unfortunately, the precautionary principle does not help much, particularly in view of the fact that the above sentence is in fact completed with 'at an acceptable economic cost'. Inevitably, economists have something to say on the matter, and the viewpoint taken by those who have discussed the issue, and that has been influential whatever the provisional conclusion being reached, relies on cost-benefit analysis.

Cost-benefit analysis involves a comparison between the cost and the benefit of an action. The cost of an action is difficult to measure, and becomes more difficult to measure the further you go into the future. For the near future, there are some models that can reliably predict the cost of meeting the Kyoto target, for example the cost to the US if it had joined Kyoto. Predicting the cost of reaching the stabilisation objective alluded to above in 2050 using the mix suggested by Socolow is more difficult, but it is still possible to have an idea.

A useful summary of the cost of action is clearly the shadow cost of carbon. This is a price signal associated with some exogenous objective. In the present context, it is the use cost of carbon which should be imposed on every activity present in the world, or focusing on the US, on every activity in the US, in order to induce people to take actions that implement the objective. Discussions of the shadow cost of carbon to meet the Kyoto protocol or to reach the 2050 objective often involve figures between €100 and €300 per ton of carbon. This gives an indirect idea of the global costs. Assume for example that the shadow cost of carbon to fulfil the Kyoto protocol for the US is $170 per ton of carbon (this was an actual average among many studies). In order to translate this into a global cost, note that the US objective if it had entered the Kyoto Protocol would have been to reduce emissions by about 2 tons per capita per year. At a shadow cost of $150, which is a marginal cost, which I suppose will rise linearly, the average cost is about half of that, which makes approximately $150 per US citizen. This is less that 0.5 percent of GDP, giving some idea of the nature of the cost.

Next comes the question of damages: if an economist has the cost he will try to evaluate the damages and provide a monetary evaluation of them – we will return to this later.

Finally comes the timing question: the costs are quite close to us, while the damages are in the distant future (the concern is for 2100 or maybe even 2500).

The next question is: How should we discount the future when comparing costs and damages?
It is not merely an economic question, but may have a metaphysical dimension, which is the opinion of two of the people mentioned in the introduction, Jonas and Dupuy. At the least, it is an ethical question and we shall return to it later.

Figure 12 shows some of the possible impacts of global warming drawn from the Stern Review. They concern water, food, health, land use, and the environment, and are associated with different average increases in the temperature on the earth[4]. Some of these damages are relatively easy for an economist to evaluate if the physical data are available. Consider for example the effect of global warming on agriculture: with a temperature increase of less than 2° some regions are better-off and others are less well-off; beyond 2° it seems that there is a generally negative impact on agriculture in all regions. If there are extreme events, the cost of reconstructing buildings is triggered. A number of the effects of the rise in sea level need to be repaired at a cost. Global warming will lead to water shortage in many regions of the world. These damages may be evaluated in monetary terms, although it becomes more and more difficult as you move from the first (agriculture) to the last (water shortage). What is even more difficult to evaluate is the effect on biodiversity, which global warming would seriously threaten. At some level of temperature change it is likely to induce large-scale migration. The costs here become more and more difficult to assess.

[4] It should be noted that damage from climate change depends on whether a country is developed or developing. On average, developing countries are much more sensitive to the change, and China, India and Brazil should be much worse affected than many industrialized countries.

Temp rise (°C)	Water	Food	Health	Land	Environment	Abrupt and Large-Scale Impacts
1°C	Small glaciers in the Andes disappear completely, threatening water supplies for 50 million people	Modest increases in cereal yields in temperate regions	At least 300,000 people each year die from climate-related diseases (predominantly diarrhoea, malaria, and malnutrition) Reduction in winter mortality in higher latitudes (Northern Europe, USA)	Permafrost thawing damages buildings and roads in parts of Canada and Russia	At least 10% of land species facing extinction (according to one estimate) 80% bleaching of coral reefs, including Great Barrier Reef	Atlantic Thermohaline Circulation starts to weaken
2°C	Potentially 20 - 30% decrease in water availability in some vulnerable regions, e.g. Southern Africa and Mediterranean	Sharp declines in crop yield in tropical regions (5 - 10% in Africa)	40 – 60 million more people exposed to malaria in Africa	Up to 10 million more people affected by coastal flooding each year	15 – 40% of species facing extinction (according to one estimate) High risk of extinction of Arctic species, including polar bear and caribou	Potential for Greenland ice sheet to begin melting irreversibly, accelerating sea level rise and committing world to an eventual 7 m sea level rise Rising risk of abrupt changes to atmospheric circulations, e.g. the monsoon Rising risk of collapse of West Antarctic Ice Sheet Rising risk of collapse of Atlantic Thermohaline Circulation
3°C	In Southern Europe, serious droughts occur once every 10 years 1 - 4 billion more people suffer water shortages, while 1 – 5 billion gain water, which may increase flood risk	150 - 550 additional millions at risk of hunger (if carbon fertilisation weak) Agricultural yields in higher latitudes likely to peak	1 – 3 million more people die from malnutrition (if carbon fertilisation weak)	1 – 170 million more people affected by coastal flooding each year	20 – 50% of species facing extinction (according to one estimate), including 25 – 60% mammals, 30 – 40% birds and 15 – 70% butterflies in South Africa Collapse of Amazon rainforest (according to some models)	
4°C	Potentially 30 – 50% decrease in water availability in Southern Africa and Mediterranean	Agricultural yields decline by 15 – 35% in Africa, and entire regions out of production (e.g. parts of Australia)	Up to 80 million more people exposed to malaria in Africa	7 – 300 million more people affected by coastal flooding each year	Loss of around half Arctic tundra Around half of all the world's nature reserves cannot fulfill objectives	
5°C	Possible disappearance of large glaciers in Himalayas, affecting one-quarter of China's population and hundreds of millions in India	Continued increase in ocean acidity seriously disrupting marine ecosystems and possibly fish stocks		Sea level rise threatens small islands, low-lying coastal areas (Florida) and major world cities such as New York, London, and Tokyo		
More than 5°C	The latest science suggests that the Earth's average temperature will rise by even more than 5 or 6°C if emissions continue to grow and positive feedbacks amplify the warming effect of greenhouse gases (e.g. release of carbon dioxide from soils or methane from permafrost). This level of global temperature rise would be equivalent to the amount of warming that occurred between the last age and today – and is likely to lead to major disruption and large-scale movement of population. Such "socially contingent" effects could be catastrophic, but are currently very hard to capture with current models as temperatures would be so far outside human experience.					

Figure 12

On this subject, the Stern review has been widely reported in the media for both good and bad reasons, but its key contribution is its anti-Lomborg effect. (Lomborg is the Danish statistician who wrote a book titled 'The sceptical environmentalist', claiming that global warming was not a very serious problem[5]).

Why should Stern be taken seriously? First it exploits a large number of earlier studies, and in addition gives an important role to what is an essential factor in the picture: uncertainty. For each scenario it looks not only at the average, but also at what might happen outside the average scenario: when an average increase in temperature is 3

[5] Lomborg had skimmed the work of some American economists, such as Nordhaus, on cost-benefit analysis: serious work but which he should not have taken so seriously.

degrees, 5 degrees of increase is still possible but the implications are entirely different. In order to make an assessment it is necessary to take into account the spectrum of possibilities and use an up-to-date probability assessment based on the most recent scientific work (which indeed provides estimates of likelihood or probabilities).

The Stern Review also takes the risk of proposing a monetary evaluation of damage from global warming. This is probably one reason for its success. It estimates costs of between 5 and 20% of GDP in 2100, and it provides aggregates of discounted damage and discounted cost in terms of GDP, stressing that the benefit of avoiding damages is much greater than the cost.

Although the Stern review clearly represents a great step forward, there are problems with its treatment of the discount rate, the question of how we should discount the future. And this has generated controversy.

The first point is that discounting kills the distant future: with a 5 percent discount rate (not huge for an economist), for spending €1 today you have to get €130 in 100 years, and even with a 2% rate you need to get €7.3 in 100 years to compensate for €1 spent today. This begs the question: Is standard discounting appropriate for long-term decisions?

Let us consider two opposing arguments. The first, which I will call ecological intuition, holds that standard discounting reflects the selfishness of the present generation and that it is ethically unacceptable. The second, which I call economic reason, argues that cost benefit analysis rightly stresses that it is useless to sacrifice the present generation to a future, and much wealthier, generation. It should be remembered that the discount rate only signals the extent to which you can transmit wealth.

How can economic and ecological intuition be reconciled? My own reconciliation has four ingredients. The first ingredient is what I call the ethical consideration. In technical terms, the pure rate of time preference (let us call it delta) should be close to 0 in the social utility function. This means that if delta equals 3%, the welfare of a generation in two centuries' time, even if it only has the same wealth as us, hardly matters. The argument to act now for this distant future generation is very weak. Nevertheless, this ingredient is included in the Stern Report, which takes 0,1 per cent. It is a necessary part of every reasonable analysis of the problem, even though it is not easily acceptable to everybody. Clearly this is one necessary condition for action, and one may view it as reflecting an ethical, metaphysical requirement.

The second ingredient is to accept that in the long run environmental goods are not private goods: they are not renewable resources and their relative scarcity increases. Although we expect private goods to expand exponentially, in the future we will still only have one planet.

The third ingredient is the fact that uncertainty lowers long-term discount rates[6]. In an uncertain world, in the long run only the worst cases matter, which means we should opt for the smallest discount rate possible.

The fourth ingredient is substitutability. If private environmental goods or climate, and private goods were perfectly substitutable (according to some given coefficient for some quantitative measure), then there would be no reason to treat environmental goods differently. On the other hand, if we consider the opposite case where they are complements, we can assume that welfare obtains from the minimum of the available quantity of private and environmental goods. In this case the situation is completely different: after a while the discount rate for private goods becomes plus infinity, and for the environmental good it becomes close to 0.

These are the key ingredients for the reconciliation of economic and ecological intuition. One should not sacrifice the present generation to a wealthier future generation. However leaving them the planet's environment in good condition is the only thing we can do for them that might, even if it is not certain, be of very high value to them.

3 - The design of climate politics.

We are dealing with a global problem of an unprecedented scale: the quality of the climate is a global public good. If one molecule of CO2 is emitted in Florence, in one week it may be anywhere in the atmosphere. The same is true if it is emitted in Singapore or anywhere else, and so emission is a global public bad, but the quality of climate is a global public good. As Nicholas Stern says in the introduction to the Stern review, we are facing the "largest market failure" (in the technical sense of economists) that has ever been experienced in the history of the world.

The Kyoto protocol brings a measure of response to this failure; an unsatisfactory but nevertheless in a sense remarkable response because it was so quick. The key features of the Kyoto protocol are: firstly that nations taking part are given quotas, which means objectives that they have to meet normally. They are rigid objectives using 1990 as the base year. The second aspect is an international market for quotas, which can be exchanged: if you do better than your quota then you can sell the excess on the world market to another country that has done less well. Thus a world market price for carbon, or rather a Kyoto price for carbon because the whole world is not involved, will emerge. Thirdly, participation is voluntary as defined in the so-called annex B.

There has been a lot of discussion of the Kyoto design, and a lot of criticism. Here we will mention a few key issues. First, representatives of ecology movements have often strongly criticised the market for permits: nature becomes a merchandise, an economic good, which is bad because big polluters can avoid action by paying (meaning that the US can avoid action by paying and that this is immoral). I do not think this criticism is valid because in a world system based on markets an efficient policy for the environment should use the markets. The disposition allows mitigation to be undertaken where it is cheapest. Although it may allow the US to pay rather than to act, it also

[6] See Weitzman (2001) for the technical argument.

allows, given the willingness to pay, the US a higher objective. (Unfortunately this turned out to be meaningless in the end).

A second topic of discussion relates to an opposition well known to economists: that of quantity policies versus price policies. Kyoto, in this terminology, is a quantity policy: it assigns a rigid objective (not for the world but for the annex B countries). An alternative possibility would be to impose a price policy, a harmonized world tax that would be levied in all countries, or in all Kyoto countries. For an economist these tools are more or less equivalent but not quite. Although it may be argued that the quantity policy is too rigid, there are also counter-arguments to the tax policy. An ironical point of history is that in the first round of the debate, Europe proposed a tax policy and the US refused. After that the US was instrumental in proposing a quantity policy. At first Europe refused the market for permits but finally the US solution was adopted. Europe became so converted to the new system that it implemented the European trading scheme (an internal European market for quotas[7]). Once Kyoto was on its way, the American administration changed its mind again and said that a tax policy would have been much better.

This is an interesting intellectual problem. One criterion is the question of what is more likely to trigger participation. A second criterion, which has, perhaps conveniently, not been taken into account, is the interaction between climate policies and the market for fossil fuels. A climate policy will have a strong effect on the price of fossil fuels. As this strong effect is not well understood, part of the economic debate is not well settled. This is my personal opinion.

As things stand, the situation is that Kyoto implements a carbon price space with a market for quotas where carbon can be exchanged at a price. However the space is too limited and does not include the whole world, so there is what can be called a leakage problem. If a very severe policy is implemented within the Kyoto space, it may be the case that industries will leave that space and go to another part of the world. This means that naturally the space will lose industry, which is an internal problem, but more importantly the change in competitiveness might even also increase pollution in the world. Under such extreme reactions, Kyoto would become a bad step because not only would it be detrimental to those who have taken it, but it might become detrimental to its objective.

The real question is how to trigger the participation of developing countries. Let us go back to Figure 10, which illustrates why this is such an important question. The diagram shows GDP per capita and emission per capita, and on one side there are all the annex B countries, with high GDP and high emissions per capita, while on the other side are all the developing countries. The diagram shows the state of affairs in 2002, but since then the total of emissions from developing countries has risen rapidly. Current estimates of the date when they are likely to overtake the developed countries have recently been revised from 2025 to 2015.

[7] Ideally, in this case, a tax policy might have been better.

The shortcoming of the limited carbon tax space is that the cheapest actions are outside the carbon tax world: there are many cheap actions in the developing countries that cannot be taken because they are outside the sphere of carbon tax. Here we might discuss clean development mechanisms, but they do not fit the scale of the problem.

This is a difficult problem because, in a sense, developing countries are right to refuse to pay for climate policy because the climate problems result from the actions of the developed countries over the last 2 centuries, not their own. One solution to this problem, which I proposed in my report to the French Prime minister, would be to give generous quotas to developing countries, putting them in the system without constraining them. With generous and/or one-sided quotas they would on the one hand be sure to get money, and on the other hand it would be a win-win solution: whatever arrangement obtains between developed countries, it is an arrangement that includes the developing countries and everybody is better-off. The question of whether this is acceptable would deserve discussion. It may not be. Probably, one condition for the developing countries to accept it would be a medium term commitment to some kind of egalitarian quotas at some far horizon, perhaps 2050.

The next question is whether strong climate policies are possible within a limited carbon tax space: whether it makes sense to do something in such a limited space as Europe. This is an avatar of the old question: can we have socialism in only one country? Can we have a climate policy in only one part of the world?

One possible response relates to the issue of competitiveness: a carbon added tax, mimicking a value added tax. Carbon could be taxed internally, de-taxed when it is exported, but taxed when it is imported (as we do with value added tax). Unfortunately however, a carbon added tax is not possible.

One possibility, for example within the European trading scheme, would be to have border quotas. In Europe there are quotas for a number of industries, so for example when steel comes in from outside a quota might be paid for (equivalent to that paid in Europe), and the quota might be de-taxed when European steel is exported. This would probably be WTO compatible, but naturally in order to implement the system costly quotas would be required, and not free ones as now. These free quotas change the price system in Europe, and the marginal cost for all industry, but they do not much change the average cost.

Another solution would be to have sectoral agreements across the world: agreements covering sectors like steel, cement or aluminium, which could be implemented across the world. This may be the most realistic approach to the problem.

The underlying question is: what is diplomatically the best way to induce developing countries to join? To use the credible threat of border tax adjustment, engage in negotiations on sectoral arrangements, or to propose non-binding quotas? These are probably questions for political scientists rather than for an economist.

To conclude, the climate is a global public good both for us and for future generations. I have evoked two interrelated questions, the pace of climate policy and the institution of climate policy. Although they are not entirely independent, they are not the same question. I will finish by saying that the climate issue is a central issue for the 21st century. When I decided to invest in this subject it was only out of curiosity, but over the past two years I have realized that the subject will be alive at least throughout the 21st century, so I made a very good investment for the future, although maybe for a too distant future. There is an interconnection between trade, development and the environment that is becoming more and more obvious. In a sense your generation is facing this problem and so we have to find a solution, building a new world order that connects trade, development and the environment.

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