Institut Veolia Environnement

The Stern Review on the Economics of Climate Change: from scientific controversy to challenges for public and private decision-making

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Preamble

A deliberate intermingling of science and geopolitics

The media success of the Stern review is related to the fact that its disquieting message on the damage caused by climate change comes not from environmentalists but from a former World Bank Chief economist commissioned by the UK Government. If implications for decision-makers are to be understood therefore, there can be no separate analysis of its content and context:

• The Stern review should be understood as ***UK-USA geopolitical posturing***. Tony Blair sees climate change as a threat on a par with terrorism for global security and imposed the following wording to the Gleneagles 2005 G8 summit: "*We will act with resolve and urgency to meet our shared and multiple objectives of reducing GHGs emissions, improving the global environment, enhancing energy security and cutting air pollution in conjunction with our vigorous efforts to reduce poverty*".

• The ***timing of the report's publication*** was chosen to influence the fourth report of the Intergovernmental Panel on Climate Change (IPCC), at the cost of scientific "risk-taking": the few published economic studies on the overall cost of climate change had surmised losses of 1% to 2% (Nordhaus, 2006), Tol (2002a, b) or Mendelsohn et al. (2004), i.e. a range of figures so low that they surprised IPCC Group II non-economist members. The fact that Stern put his reputation as a first-rate economist behind very high figures somewhat changed the situation at the time of drafting the Group II Executive Summary.

• This ***mixture of science and politics*** produced strong reactions. Apart from the usual people involved in the climate debate, first-rate economists such as Martin Weitzman or Partha Dasgupta intervened. The most critical accuse Stern either of issuing a political report or of basing a sound case (speed is of the essence) on faulty arguments (we know how to predict damage sufficiently to quantify them). It is interesting however to note that the general trend is to say that, however criticizable, ***Stern can be credited with making explicit the reasons for an alternative policy to that proposed by Bush*** and that his position is ***supported by four Nobel Prize for Economic Science Laureates***, and not the least among them (Robert Solow, James Mirrless, Amartya Sen, Joseph Stiglitz).

• Finally, it is symptomatic that controversy focused on damage assessment although it represents only 20% of the report. Yet, ***the issues relating to the cost of preventive decarbonisation and to the principles of international coordination of climate policies are just as important.***

• We will rectify that imbalance hereafter by discussing the Stern review both on the issue of damage and of decarbonisation policies, after which we will come to the strategic consequences to be drawn for economic actors.

Three questions on the Stern Review

Is the "Stern" message on climate damage credible?

First, a distinction should be drawn between the five chapters of the Stern review devoted to a detailed diagnosis of the risks linked to climate change, and the sixth one (Economic Modelling of Climate Change Impacts) which assesses their monetary cost. One may wonder if the assessment is meaningful in view of the uncertainties linked to such a distant future. However, the context should be understood: it is typical of an Anglo-American tradition of cost-benefit analyses which requires the cost of damage and the cost of prevention to be expressed in the same units, and which helps to shape international debates. Neither should one forget the contents of the five other chapters which highlight the challenges and opportunities of the climate issue for economic and social actors.

Influence of a seemingly abstruse debate on the choice of coefficients

Stern measures damage in terms of 2005-equivalent per capita consumption, the logic of which should be understood. It implies drawing readers into developments which may appear to be a modern form of the debate on *how many angels can dance on the head of a pin*, but which expresses in learned terms very real arguments and visions of the world.

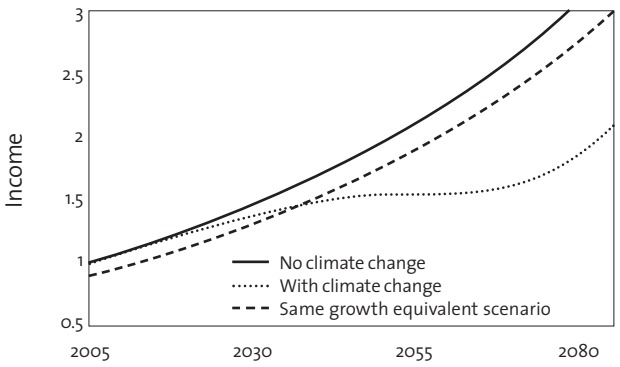
• The strong point of the Stern indicator (Annex 1 of the Stern Review) is that it puts forward a ***permanent cost***, a simple figure which summarizes loss profiles over a century: i.e. a sequence of damage occurring between 2050 and 2150 which lowers the level of household well-being (for example 2% in 2050, 5% in 2080) compared

to a given reference (1.3% growth per annum). Stern aggregates the losses over two centuries and calculates which drop in consumption today (following a hypothetical shock) would produce the same aggregate loss in well-being if it was followed by a 1.3% growth rate. It is as if n% of consumption was lost ***"now and forever"*** (see box below).

For each scenario calculation is as follows:

- sum of utilities of consumption flows between 2005 and 2200; the following fact is taken into consideration: if Peter is richer than Pedro, one extra euro on his bank account increases his well-being less than the same euro in Pedro's pocket.
- decreasing weight assigned to each of the utilities as time elapses; it is the pure present preference rate (pppr).
- determination of the equivalent per capita consumption in 2000 which, allocated the same growth rate, would produce the same aggregate utility as the previous calculation.

The starting point is a damage-free base scenario (here, 1.3% on average over two centuries, the solid curve). In scenarios with damage, income growth is lower (dotted curve). An equivalent scenario is created (dashed curve) in which income increases at the same rate as in the damage-free scenario, and which produces a utility equivalent to the scenario with damage. The difference in the 2005 income between the scenarios with and without damage provides the so-called ***permanent*** cost of climate change.



Box 1 :
Calculating the "permanent cost" of climate change

• The ***calculation depends on the long-term discount rate "r" which allows evaluating future well-being gains or losses at equivalent current values.*** They are the consumption drop or surplus needed today to achieve that gain or loss following on the change in investment which would ensue. The r value derives from the $r = \rho + \eta . g$ equation which represent ρ in a very abstract way ***interactions between preferences and technological progress:*** ρ is the pure present preference rate (ppp), and $\eta . g$ the well-being gain from the investment. That in turn is the product of η, surplus consumption, and g which describes how marginal utility decreases with income (if future generations are richer, one euro will be of less utility). Hence the importance of ρ (the value assigned to the future) in view of the time lag between emission abatement and avoided damage: if the now and forever cost of damage in 2100 is assessed at 5% of present consumption with ρ=0.1% as chosen by Stern, it rises to 0.75% with ρ=2 %, a value often retained for growth models.

• Stern justifies his choice with ethical considerations on the ***rights of future generations*** ρ: in 2100 they represent 0.82 times the 2005 generation as opposed to 0.13 with ρ=2%. The realism and the ethical nature of such a low ppp are somewhat questionable: in a growth model, such an interest shown in the future leads to recommending high immediate savings rates, in other words ***sacrifices for present generations*** for the sake of "a non rosy future". We should recall that in the fifties it was to avoid being tempted to impose too large immediate sacrifices for the sake of "a rosy future" (the scenery was dominated at the time by debates on the primitive accumulation patterns of real socialism) that economists (Koopmans) adopted ppps of 1% to 3%.

• ***The debate is partly ill-founded*** since it can be considered that a very low ppp merely ***offsets the biases relating to the tools used*** and to the limitations of state of the art economic analysis in the field:

- ***absence of the environment in the utility function:*** the function (U(C)) cannot clarify the choice between passing on to our descendants more consumption capacity or a better quality of the environment in order to help them. If our descendants are richer, the marginal utility of their consumption will be lower and they will attach greater relative value to the quality of the environment. Suppose, by way of illustration, that our descendants can only live in the Nordic area because the rest of the planet has become uninhabitable. We would have deprived them of access to a whole natural environment, in spite of the fact that they would have considered it of great value. To take into account a preference for a stable climate (or a reluctance for a Faustian wager with the planet) the environment should have been included in

the utility function.

- ***inadequate consideration of risk-aversion:*** Stern uses a Monte-Carlo draw of multiple scenarios and calculates the mathematical expectation of losses. Since the marginal utility of income decreases, a scenario which provides for an income of 100 (following severe climate damage) weighs more, in such a calculation, than a scenario with an income of 110. However, it does not allow comparison of a low risk 100 scenario with a scenario featuring an average of 120 but a huge uncertainty regarding climate risk. Normally, at this stage, another function should be introduced allowing a comparison of more or less risky draws (the so-called Von Neumann – Morgenstern function); its curvature ζ would display risk-aversion. It is usually higher than one (2 for Gollier 2007) which increases the current value of risks. But at present there is no simple way of including such a function in a model that can be calculated on a minimum empirical basis, nor is it possible to proceed as if it were sufficient to simply increase the value of η. Doing so would result in a higher discount rate which would reduce the value of future risks. We can only take note of the limitations of current economic analyses in one important aspect: clearly, the same loss of economic value will have a greater impact on the well-being of an Indian than of a European. However, Europeans are richer and are more adverse to climate risk, so that one can state from experience without the slightest cynicism that certain "accidents" affecting some hundred of them can have a greater media and political (and therefore economic) impact than if the same accidents affected twenty times as many "poor" people.
- ***underestimation of the value of the risk of "disasters"***: the distribution of Monte-Carlo draws displays ex ante probabilities of rare but disastrous events; since such events are very rare, they count for little in the calculation of the mathematical expectation of damage. In this, Weitzman's criticism is relevant when explaining that standard treatment (normal law) is inappropriate for phenomena with infinite variance. Monte-Carlo draws underestimate the probability of disastrous events and the actual distribution of risk may display "thick tails" instead of dropping to zero as is the case for rare major risks used by most analysts.

A precise and disquieting diagnosis of actual risks

Possibly because the debate has focused on the current value of damage, the fact that N. Stern provides an impressive overview of the links between climate change and economic vulnerability may have been overlooked. Quantitative assessments

are necessarily fragile but there is a good description of the mechanisms explaining that there is little chance of our societies adapting smoothly to rapid developments which are increasingly likely following on recent upward revisions of climate sensitivity (possibility of a 10°C warming). ***In addition to major disasters such as the slowing down of North Atlantic thermohalyne circulation***, the main risk vectors can be summarized briefly as follows.

• ***Water, a major vector of fragility***: differences in water availability are sharpening alarmingly: 30% loss in sub-Saharan Africa and South America for 2°C of warming (40% to 50% for 4°C) and a 10 to 20% increase for Russia, South Asia and Northern Europe. Some 1.4 billion people will suffer from water shortage (Africa, Middle East, Southern Europe, some Latin American areas)[1]. Based on this overall picture, unsurprisingly, one may note:

- The consequences of melting glaciers for water availability (500 million people affected in the Ganges valley, 250 million in China, 10 million in the Andes) and infrastructure (sudden overflowing of glacial lakes which destroyed 14 bridges of the Namche hydraulic project in 1985),
- Extreme events (long droughts and floods); in addition to infrastructure costs, Stern stresses less tangible parameters such as social structures adapted to a given rainfall pattern (in India for instance for monsoon cycles which up to now were fairly regular),
- The combined impact on agricultural productivity of water shortage, traditional pollinator decline, pest proliferation, and more frequent heat waves.

• ***Food, rising tensions***: in the 21st century, agriculture will continue to feed the high proportion of world population living with less than 2$ a day, and the social weight of the sector exceeds by far the 3 to 5% of economic GDP it represents in developed economies, if only because of the impact of a huge food price increase on household purchasing power. The lengthening of the growing season, the extension of available land and the carbon fertilising effect resulting from 1°C of warming are more than offset by the disturbances caused by water cycle alterations. Global cereal production may drop by 5% for +2°C and 10% for +4°C (disregarding extreme events and higher O3 troposphere concentrations resulting from acid rain in Asia where coal will predominate). The most vulnerable country is Australia (which is experiencing its longest ever drought, i.e. six years from 2001 to 2007, in the south and south-east where 85% of irrigated farming is concentrated). Africa and West Asia may see their production

[1] Stern adopts a threshold of 1000 m3/per capita/annum for severe shortage, and 500 for absolute shortage with 20% to 50% available for human use, 30% "lost" and 20% to 50% used by ecosystems.

drop by 25% to 35% for a 3° to 4°C rise in average temperature, and famine may affect 500 million more people. To this should be added ocean acidification which threatens shell and skeletal formation; a drop of 0.15 pH units (for 560ppm) would severely affect the marine trophic chain, particularly by halting coral formation. And yet one sixth of the world population depends on sea products.

• ***Human health***: just as with food, there will be gains in some regions (lower cold-related mortality in Nordic areas) and deterioration in warm areas (according to WHO estimates, there have been 150,000 extra deaths on average per annum since 1970 because of climate change). Global warming alters the geographical extent of pandemics and water is a major vector, particularly for the increase in tropical diseases (after Hurricane Mitch in 1998, Honduras experienced an extra 30,000 cases of malaria and 1,000 cases of dengue fever) and accidental deaths (dehydration and drowning). An additional risk factor is the extension of areas close to the critical threshold for humans, such as the Ganges plain (45°C daily average). Whereas it may be argued that it is possible to control the cost of tropical diseases by providing free medication (which implies settling the controversy with the pharmaceutical industry), this damage can only be remedied by relocating people (150 to 200 million in 2050).

• ***Infrastructure costs and systemic shocks***: this is one of the review's central messages showing similarities and differences between developing and developed countries, and leading to the concept of "systemic shock" caused by migration and the weakening of the insurance and financial industries:

- *Rising sea levels*: 200 million people live in coastal plains and the value of assets located less than one meter above sea level is estimated at 1,000 billion euros. This includes 22 out of the 50 largest cities in the world (including London and New York) and one quarter of the population of Bangladesh. The report estimates that 7 to 70 million people will experience floods every year with 3°C of warming and 20 to 300 million with 4°C, which of course calls for expensive protection measures. The most vulnerable areas are Bangladesh, the Nile delta, and the Caribbean and Pacific islands.

- *Extreme events*: their direct impact is the need to rebuild infrastructure (hurricanes, floods) or to urgently adapt them (droughts, heat waves). However, over one fourth of developed countries' investment is devoted to construction, to which must be added transport and production infrastructure, energy transmission and distribution (mostly electricity). Insurance business statistics, as well as events such as Katrina,

floods in Germany and Central Europe or the 2003 European heat wave, indicate that even a slight increase in the intensity of hurricanes or tidal surges would generate sizeable costs.

- *Systemic shocks for the financial and economic system*: the increased need for repairs and damage compensation (including loss of agricultural and tourism income) raises such a serious problem for insurance and reinsurance companies that they are searching for new products (weather derivatives, catastrophe bonds). To avoid systemic risks for the financial and banking system, one could contemplate either lowering significantly the basis or rate of coverage, or transferring the disaster burden to "ordinary risks", hence a transfer of the shock to the industry (which could then greatly cut risk-taking).

• ***acceleration of migratory flows and risks of conflicts***: migratory flows are described by N. Stern as one of the major and least controllable consequences of climate change. In developed countries, he notes a "northward shift" without dwelling on the political risks generated (possibly challenging national solidarity in Spain and Italy for instance). He does however insist, quoting numerous past examples, on potential conflicts linked to water, sudden drops in subsistence farming productivity, rising sea levels or infrastructure loss resulting from extreme events. That is probably the core of N. Stern's message, thus concurring with a longstanding British Government analysis.

Robustness of Stern's conclusions as to the need for immediate action

The Stern review is mostly criticized for its economic methodology. It may indeed be regretted that its overall evaluation depends on such sensitive and abstract parameters as pure preference for the present or the curvature of the utility function. We saw that one way of overcoming the limitations of the model used was to choose a low ppp, to which should be added a large amount of non-market damage. However this in no way invalidates overall conclusions that can be supported by methods less sensitive to a few inescapable (because they include some of the real dimensions of the problem) but very fragile parameters.

• In a context of extreme uncertainty ***the problem does not lie in guessing the value of damage in order to decide today which is the right emission path to choose for the current century***. In fact such an exercise would not stand the slightest chance of leading to a consensus in the foreseeable future in view of the highly controversial nature of the physical, economic and ethical parameters of the calculation. The aim

is to reach a compromise over the next twenty or thirty years between contrasting positions (from Greenpeace to Claude Allègre) until more is known. Therefore, even with the usual ppps, introducing a meaningful probability of thresholds beyond which damage increases significantly (even if it means stabilising later at a non-catastrophic level) is sufficient to conclude that immediate action is required. Such thresholds move forward in time in case of strong climate sensitivity, and we find ourselves in the situation of a motorist who does not know if the next bend is icy; the driver taps the brake pedal to be able to slow down if needed without wasting too much time in case the ice has melted. The car's momentum must not take over and a margin of adaptation must be preserved.

• ***The existence of such thresholds does not depend solely on physical mechanisms.*** It depends mainly on the cost of adapting societies to climate change, and on the three following crucial parameters: (1) infrastructure sector inertia; (2) the spreading of sporadic economic imbalances to the economy as a whole; (3) the effect of international destabilisation. These are multiple factors that explain the possibility of "thick-tailed distributions" (Weitzmann 2007), i.e. risks whose probability tends towards zero but not fast enough for their mathematical expectation to tend towards zero.

• The problems of ***internal and international security*** in that context are a central element, already mentioned by Homer-Dixon (1991). The issue is not that there are international crises caused only by an environmental problem (e.g. Gleditsch, 2006), but that climate change will exacerbate pre-existing tensions, if only through waves of "climate refugees". The causes of migration are water scarcity, rising sea levels (Bangladesh, Egypt), or both (small islands becoming more vulnerable to storm surges and whose fresh water resources are jeopardized by increased salt content). The psychological and social costs of such forced migration can be very high, as suggested by the U.S. Dust Bowl in the thirties, Hurricane Katrina or Hurricane Mitch in Honduras. Managing such movements will be a challenge for the international community, and recent experience on a smaller scale is not conducive to optimism.

How should Stern's vacillations on decarbonisation policies be interpreted?

The Stern review contains nothing dramatically new regarding decarbonisation poli-

cies. He recommends an objective of 550 ppm (all gases included) which the E.U. advocates, and adopts the consensus of economists on the need for an international carbon price. This leads him to reassert the relevance of the Kyoto system to implement a policy that is efficient while including a concern for equitable burden-sharing. But closer reading reveals qualified and inconclusive statements on sensitive issues, and a distinction should be made between firm and more hesitant stands.

• Stern adopts a figure of -1% of GDP in 2050 as the cost for emissions paths stabilised at concentrations of 550 ppm. This is an average between -5 and +2% as provided by existing models. Stern insists on the fact that the figures will not be attained without a rapid learning process of carbon-low technologies.

• It allows him to assert that the cost of a ***550 ppm objective is strongly justified*** by avoided damage. But he hints that a target of ***450 ppm would be desirable*** to keep warming between 2°C and 3.8°C. Because of the upward revision of climate sensitivity, 550 ppm would lead to temperature rises between 1.5°C and 4.7°C above pre-industrial levels.

• Achieving these objectives is conditional on the ***rapid emergence of a carbon price***, whether explicitly (taxes or tradable emissions rights) or through normative action. The Kyoto Protocol allows this while leaving every government free to choose its own internal measures, and using quota allocations as a tool to deal with issues of equity between countries. It considers the European trading scheme (EU ETS) as a prototype for a carbon market but noticeably draws a distinction between such a local and partial scheme and an interstate system based on national quantitative commitments.

• After insisting on the fact that there are strong reasons for ***building an international scheme based on Kyoto instead of attempting to replace it***, Stern introduces several ***qualifications***:

- Regarding the EU-ETS, he insists on the need for clear allocation rules for future commitments so as to increase system predictability for investors as the only guarantee of efficient technological choices. However, after explaining it is almost impossible to develop equitable, efficient and robust inter-country rules, he does not take a stand on the issue of whether such an approach (described as "cap and trade") could be used to accelerate the inclusion of developing countries.

- He does however mention the need for ***convergence between various initiatives*** (in or outside Kyoto, at country or industry level), by organizing allowance trading schemes between them. Allowance levels and trade flows would eventually make the initiatives comparable.

- Implicitly, this means ***keeping Kyoto at the heart of the system but abandoning the***

idea of getting the USA or developing countries on board. This is typical of UK diplomacy: adhering to the European consensus to exert pressure on the United States, while including from the outset what they think the Americans cannot accept for a given period. However, applying Kyoto (partly) as such depends on a quota agreement within a group of countries representing a minority in global emissions and who might be penalized in terms of competition.

• ***For developing countries, Stern proposes "risk-free" quantitative commitments***, i.e. without penalties in case of non-compliance. But raising the 20 to 30 G$ annual investment required to redirect the content of infrastructure to be built over the next 20 years will not be possible with this method. The Kyoto framework would need to be supplemented by ***new carbon-related financial mechanisms*** (including investment risk insurance) to allow the private sector to participate in the funding of structural policies and programmes, and not just projects as in the Kyoto Protocol Clean Development Mechanism (CDM).

• In addition, ***R & D investment in carbon-free technology (34 million $/annum currently) will have to increase two to fivefold***. One sensitive issue in this regard is intellectual ***property rights***. Stern, for reasons which again have to do with diplomacy, insists on the fact that those rights are not the only key barriers to the transfer of technology, and that innovative systems of technological cooperation and public private partnerships must be sought. However, in doing so he opens the way to possible considerations without providing a formal solution.

• N. Stern does however take a ***firm stand against the imposition of border taxes*** in order to avoid industries in the most ambitious countries in the field of decarbonisation policies being penalized compared to those countries that make purely token commitments or no commitments at all. His point is that such taxes are the most efficient instrument in theory, but that attempting to introduce them would trigger retaliation measures that would threaten the opening of global markets, worsen difficulties in advancing WTO, and might even spark off protectionist withdrawal. Here again, we recognize the consistent UK diplomatic position.

What are the challenges for economic actors?

The Stern review, with a more committed message than the IPCC's, alerts us to the implications of climate change, be it the risks involved in the change or the mitigation

policies adopted. The issue will weigh on the business environment, if only because of possible remedial policies whose content will depend on highly geopolitical diplomatic processes. However, the preceding section highlights that it is infrastructure industries and providers of essential services that are mainly concerned. They are engaged in businesses that are characterized by very long term vistas so that present decisions determine to a great extent our margins for manoeuvre by the end of the century.

• The challenge is to design ***infrastructure integrating the decarbonisation imperative while supporting adaptive strategies to changes in local climate throughout their lifetime***. Therefore, architects must design low net energy intake buildings while planning their adaptation to a wide range of temperature, rainfall and extreme event variations over more than 100 years; electric power generating companies must switch to alternative energies (and/or carbon storage) while taking into consideration changes in water availability and sea levels over the lifetime of a power plant (60 years); energy transmission and distribution network managers will have to minimize network losses while improving equipment resilience to climate uncertainties; the transport industry will have to provide a credible alternative to private car travel and air transport. Other actors, as in the water industry for instance, are less concerned by mitigation policies (except through the electricity or agricultural sectors) but will be in the front line for adaptation.

• Since uncertainty regarding climate change is greater on a regional scale than on a global one, and since local climate alterations will be concealed by natural variability, ***detecting climate change*** will be particularly difficult at local level, the only one which is relevant for adaptation. Consequently, necessarily less carbon-emitting infrastructure capable of withstanding a wider climate range will have to be designed (see three examples in Annex 1 of the Stern Review), but they will be more complex and more expensive. Public-private interaction will have to be adapted accordingly in the infrastructure sector (local and regional authorities, government, and businesses) in order to ***improve their proactive capacity*** so that controversies unavoidably linked to uncertainties do not lead to a policy freeze.

• The economic challenge is huge, as are the ***economic risks and opportunities.*** In developed countries, infrastructure represents about 300% of GDP, and replacing just 1% each year would cost 3% of GDP annually. In developing countries, infrastructure stock will double over the next two decades. On the one hand, short- and medium-term choices will rapidly determine achievable concentration objectives, on the other, the vulnerability of economies to even slight impacts on infrastructure is widely underestimated today; the damage inflicted by Hurricane Katrina represents "only" two weeks' investment in the United States, but its local impact is much larger if

technical, economic and human constraints linked to reconstruction, spillover to the regional economic fabric and the irreversible effects of such a disaster are taken into account. Annex 2 of the Stern Review puts forward a number of economic mechanisms that need here to be taken into consideration.

• All this leads to both new market opportunities for ***infrastructure industries or essential services*** and greater ***social accountability*** from two aspects: proactive, by recommending and helping to anticipate climate change, and reactive, to avoid rising political and legal challenges. Such challenges may of course relate to the incapacity of companies to supply suitable equipment but also to the fact they compounded the problem through their emissions (the debate on the "allocation" of responsibility for climate change). Similarly, actors involved in reconstruction will be faced with more pressing demands and their capacity to respond will be crucial. The difficulty is that companies cannot go too far without regulations being adopted by governments and the international community.

• ***For decarbonisation policies, the real risk is uncertainty regarding policies*** adopted at national, European and international levels. The last fifteen years have shown the extent to which the international negotiation process consists in a series of diplomatic compromises and lobbying actions whose ultimate consequences are poorly controlled (Hourcade). The role of industry is to exert its influence to emphasize the need for stable and recognizable compromises in order to ensure safe investments in carbon-low projects and technology. In that context, in addition to sustained attention paid to the debate on the future of a "cap and trade" system after 2012, one of the challenges is to rapidly develop international financial mechanisms that may interest developing countries in setting up infrastructure adapted to strong "carbon constraints". It is indeed very likely that the price of carbon and the income it generates will not be high enough initially to incite developing countries to drastically change direction in infrastructure sectors where carbon prices are only one of the parameters.

• ***For adaptation, the central issue is the financial, institutional and insurance context***. On the one hand, international disaster relief should play an increasing role by extending the emergency phase (the weeks following a disaster) to the reconstruction phase which can spread over several years. More particularly, original reconstruction funding methods could be developed, drawing inspiration for instance from the agreement between AXA Ré (now Paris Ré) and the United-Nations World Food Programme to respond rapidly to humanitarian climate disasters in Ethiopia. On the other hand, making technical expertise and equipment available to affected countries (whether rich or poor) might accelerate reconstruction, thereby contai-

ning short- and long-term costs. Urgently restoring drinking water supplies is a prerequisite to reconstruction, but additionally water management infrastructure is part and parcel of the reconstruction process and boosts economic recovery. All in all, the heterogeneous nature of the increased risks which hit the poorest countries hardest calls for stronger international cooperation. Building such cooperation may imply insurance mechanisms or international funds such as the Adaptation Fund established by the Kyoto Protocol whose modes of implementation were discussed recently in Nairobi.

Three key elements on the nature of climate risks

Interactions between inertia and uncertainty in the infrastructure sector

Housing stock is one example where uncertainty regarding future climate and/or infrastructure inertia plays a key role. Turnover time for buildings in France, for instance, is around 150 years. So buildings erected in the first decade of the 20th century should be designed according to the prevailing climate up to 2150. But that climate is still unknown: according to the Météo France model, the Paris climate in 2080 will be the same as the present one in Bordeaux, but according to the Hadley Center model, it may be closer to the present climate in Cordoba in southern Spain. Both models therefore suggest the use of radically different optimal building standards. If we knew today what the future climate will look like, the inadequacy of the housing stock would be easy to manage because a slow and inexpensive adaptation process could be initiated immediately.

The uncertainty-inertia pair therefore makes perfectly anticipated adaptation very unlikely. Even though a proactive strategy appears rational, by improving housing insulation standards for example, the risk of significant short-term costs to reap uncertain and far-off gains means it would be politically difficult to implement. For instance, faced with structural housing shortages in France, no government can

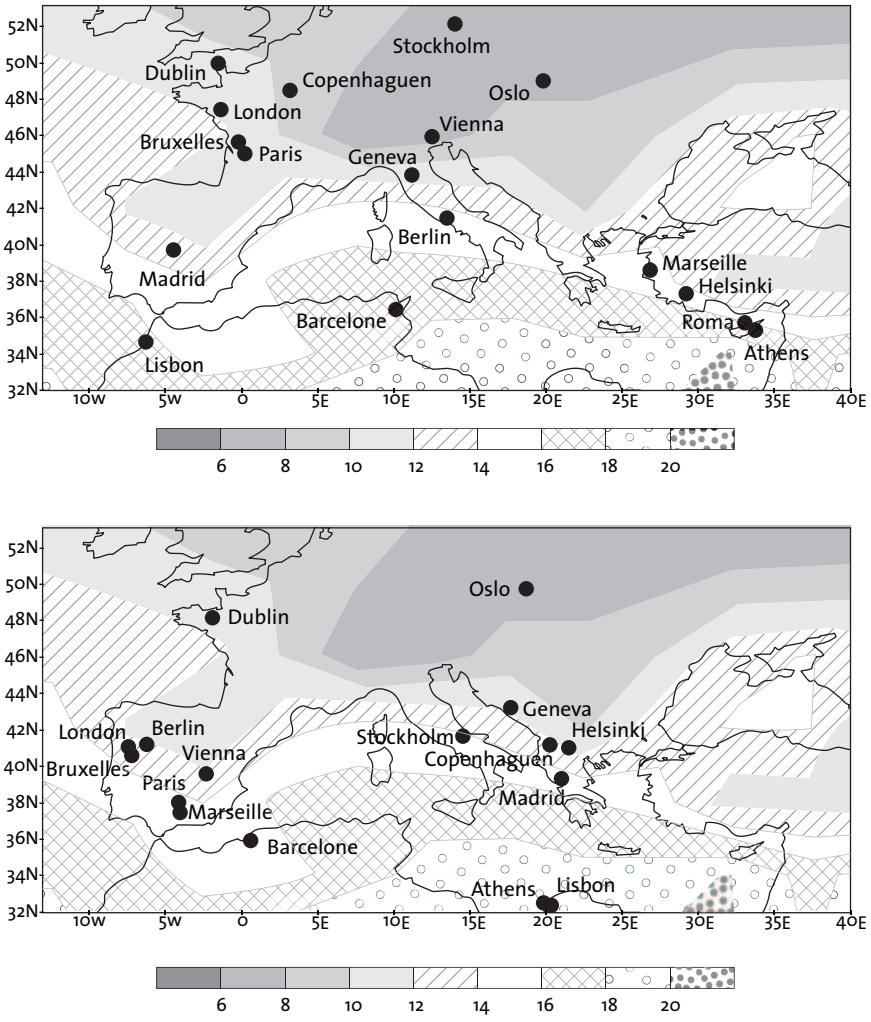


Figure 1 :
Climate analogues for some European cities. Each one is located where the present climate is comparable to what it will be for that city at the end of the century, according to the Météo-France model at the top, and the Hadley Center model at the bottom. Two climate patterns are supposed to be comparable if they have the same temperature and rainfall seasonal cycles. From Hallegatte et al, 2007, Climatic Change.

afford to implement measures that would put up construction costs, specially if it only means mitigating climate damage in fifty years' time. Consequently, part of the housing stock stands every chance of being ill-adapted well before the end of the century. It would result in French cities becoming less attractive[2], and this may have a very negative impact in a world where major cities are in competition to attract businesses and corporate managers.

The protection system for New Orleans is another example. Its reconstruction is being considered and it will shape the city for more than a century. What is the likelihood of a category 5 hurricane striking the city around 2080? No one knows the answer, which makes it very difficult to determine the scale of the protection system (see Hallegatte, 2006 and Fig. 2). In addition, the fact that the city withstood Hurricane Katrina very badly shows it is not enough for all the parameters to be well known for rational decisions to be taken. With parameters made much more uncertain because of climate change, poor adaptation is even more likely.

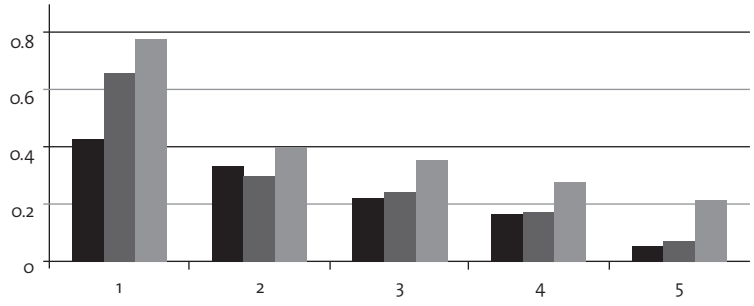


Figure 2 :
Annual probabilities for a category 1 to 5 hurricane striking the American coastline, 1900-2005 data (in black), according to the K. Emanuel model for current climate (in dark grey), and according to the same model for a 2°C warmer climate (in light grey). The probability for category 5 hurricanes increases more than threefold. Large uncertainties remain concerning these results and other models find an unchanged probability, which shows the substantial uncertainty that makes determining the scale of the New Orleans protection system difficult. From Hallegatte, 2007, Journal of Applied Meteorology and Climatology.

[2] Similarly, how attractive would South California be, knowing that temperatures could rise to 120°F each summer and that water could be expensive and rationed? Taking things further, how can California as a whole and its neighbouring states adapt their economies to a drop in attractiveness of the South Californian heartland? Here again, infrastructure managers will have a key role to play in impact-mitigation.

One final example concerns rainfall variations observed in southern Argentina. To date, there is no clear-cut explanation for the anomaly: it is not known whether it results from climate change, in which case it is permanent, or from natural climate variations, in which case it is temporary. Farmers are therefore wondering whether to adapt by changing activities (switching from agriculture to breeding) or by investing massively in irrigation equipment, or if they should wait for the anomaly to disappear. Uncertainty as to future local climate is the main obstacle to optimal adaptation of the activity and therefore it generates significant costs for such a key sector of the Argentinian economy.

One of the consequences of the mechanism results from the fact that large uncertainties make anticipation, often revised when a crisis occurs, highly volatile. In another area of large uncertainty, we saw that one pair of diseased birds played havoc with the poultry sector because they engendered fear of a significant spread of avian flu. Similarly, one or two heat waves could easily give the impression that a large percentage of the housing stock will become uninhabitable because of climate change. True or not, such revised anticipation could well bring down house prices.

In conclusion, in a comprehensive assessment of impact and adaptation mechanisms, imperfect anticipation may lead to long periods of non-adaptation in high inertia sectors, with significant economic consequences. For an analysis of climate policies, these mechanisms render inadequate any climate change damage assessment that does not explicitly represent adaptation mechanisms that include the technical, cultural and institutional constraints governing our societies and our economies.

Problems in assessing the cost of natural disasters

Working on disaster consequences is fraught with several specific difficulties. In particular, in economic equilibrium models, which by design cannot represent short time-scales, extreme events can only be taken into account through a fall in mean productivity. But disasters mainly affect the life and well-being of people, and destroy productive capital and buildings. Modelling disasters by reducing productivity or destroying capital would only be the same if the impact of disasters could be "averaged" over long periods. Yet that would only be possible if the impact of disasters was linear compared to the event's intensity, which is clearly not the case (see New Orleans after Katrina, RMS, 2005).

In order to make up for this underestimation, and represent natural disasters in a manner consistent with observations, short-term constraints in direct consequences

and reconstruction rates need to be considered. Without these constraints, the damage inflicted by all disasters, even the most severe, would be repaired in a few months which is contradicted by actual case observations. (e. g. the 1999 storms in Europe, the 2002 floods in Central Europe, and the 2004 hurricane season in Florida). There are strong financial constraints applying to reconstruction, particularly but not exclusively in poor countries, as well as technical constraints, such as the lack of qualified workers and building equipment. We have numerous empirical examples of the existence of such constraints which are also responsible for what is called "demand surge", i.e. price inflation for the goods and services required for post-disaster reconstruction. These constraints may considerably increase the total cost of an event. For instance, operating losses during actual reconstruction time must be added to the cost of a ruined factory. Similarly, in the housing sector, the destruction of a house which takes a year to be rebuilt has a total cost equal to the replacement cost of the house plus lost value relating to one year of "housing service". The value of production losses in the widest acceptance can be very high in several sectors, specially when basic needs are at stake (housing, health, jobs, etc.). Applied to the economy as a whole, the difference can be huge for large scale disasters.

These constraints may provide an explanation for "poverty traps" in which some poor countries seem to be caught: since they are poor, they have a low capacity for reconstruction after each disaster. Because they have such a low capacity and are widely exposed to dangerous events (tropical hurricanes, floods, droughts), successive disasters may hinder them from accumulating infrastructure and capital and therefore from developing their economy which would improve their post-disaster reconstruction capacity. Development agencies recently acknowledged the problem when they asked for risk management to be consistently included in development projects.

These constraints may also make the economy highly vulnerable to an increase in disaster intensity and/or frequency. The impact of climate change could well lead to an extension of these poverty traps. This is not inevitable however since specific economic adaptation may increase reconstruction capacities and ease constraints. Mention can be made of changed regulations for the insurance industry (e. g. Solvability 2 in the EU), the development of government-funded insurance schemes (e. g. the *Florida Hurricane Catastrophe Fund* or the "Cat-Nat "system in France), and the spontaneous growth of production capacity in the reconstruction industry in response to rising demand and the increase in interregional and international aid, which should extend from the emergency period to the whole reconstruction period. The way in which some of the private and public economic actors manage escalating risks will, to a large extent, determine their macroeconomic cost.

Political costs of environmental disasters[3]

In the past, some disasters had destabilizing consequences. Hurricane Bohla devastated more than half of East Pakistan in 1970 (over 200,000 fatalities), and the ineffectual rescue operations organized by the central government headquartered in West Pakistan caused instabilities which led to the creation of Bangladesh in 1971. Of course, Hurricane Bohla is not alone in bearing responsibilility for the event, but it was clearly the triggering factor. Climate events have also often sparked off rapid urbanization phases, as with the "Dust Bowl" in the thirties in the United States. Uncontrolled urbanization is well-known major cause of social fabric breakdown, and this in turn facilitates mounting criminality and political destabilization. In Darfur, even if the political situation is immensely complex, the present conflict opposes sedentary farmers and nomadic cattle-breeders who are in competition for water and grazing land in a context of increased environmental scarcity. These conflicts, which today are caused by an interaction between population growth and resource depletion, may well become more frequent with the change in climate which is going to render most traditional lifestyles and social organizations obsolete.

At an international level, things are somewhat different. Concerning water resources for instance, international management leads more often to cooperation than to conflict (Wolf et al., 2003). Yet, population growth and climate change may well worsen existing tensions. Lonergan and Kavanagh, (1991), or the *Transboundary Freshwater Dispute Database*[4] provide examples of this kind of tension, such as between Egypt and Ethiopia which controls 82% of the water flowing into Egypt, or between Iraq, Syria and Turkey for the Euphrates. So long as people's *fundamental needs* are not at stake, the tensions are manageable. It is however likely that water and climate change will play a major role for the future of semi-arid zones. But even if resource-related conflicts have seldom sparked off international crises, they often create domestic tensions, and the cost of these internal conflicts can soon become significant.

The other major problem is that of "environmental refugees". According to Myers (2001), who is however considered to be rather pessimistic, there could be some 210 million refugees because of global warming by 2050, including 160 million because of rising sea levels (73 in China, 26 in Bangladesh and 20 in India), and 50 million because of droughts and water shortages. Six million people for example live at present in areas that would be flooded in case of a one meter rise in the Nile delta sea

3 Note the special issue on this subject of "Cahiers de la Sécurité" (number 63), published by S. Hallegatte and P. Ambrosi.
4 http://www.transboundarywaters.orst.edu

level, and 4,500 km2 of excellent arable land would also disappear. The estimates for Bangladesh stand at 17 million people and 22,000 km2, i.e. 15% of the population and 16% of the country's area. For small islands the situation is even more tragic since entire countries might disappear because they would not be able to withstand tropical storms if sea levels rise by one meter, or because of insufficient fresh water resources if the trend towards increased salt content persisted.

Climate change, from risks to opportunities

In spite of the reservations it has inspired, the Stern review is symptomatic of a context in which climate change can no longer be denied as a major issue on the international agenda (even the Bush Administration has conceded the point), if only because of its implications in terms of global security, and, by symmetry, because of the impact of climate policies on energy markets (dropping oil and gas rents caused by the emergence of a carbon price).

This context also creates a whole set of opportunities, both in developed and developing countries, the challenge being to transform economies so as to cut greenhouse gas emissions while making them less vulnerable to changing and at times extreme environmental constraints. However, some of these opportunities will only arise in the framework of international measures dedicated to climate change adaptation, such as the Adaptation Fund adopted in Bali in December 2007, and of credible and predictable post-Kyoto schemes.

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Abstract:

The media success of the Stern review is related to the fact that its disquieting message on the damage caused by climate change comes not from environmentalists but from a former World Bank Chief economist commissioned by the UK Government. If implications for decision-makers are to be understood therefore, there can be no separate analysis of its content and context.

The Stern review should be understood as UK-USA geopolitical posturing; the timing of the report's publication was chosen to influence the fourth report of the Intergovernmental Panel on Climate Change (IPCC), at the cost of scientific "risk-taking"; and finally this mixture of science and politics produced strong reactions. The most critical accuse Stern either of issuing a political report or of basing a sound case (speed is of the essence) on faulty arguments (we know how to predict damage sufficiently to quantify them). It is thus symptomatic that controversy focused on damage assessment although it represents only one fifth of the report. Yet, the issues relating to the cost of preventive decarbonisation and to the principles of international coordination of climate policies are just as important.

The present analysis will rectify that imbalance hereafter by discussing the Stern review both on the issue of damage and of decarbonisation policies, after which it will come to the strategic consequences to be drawn for economic actors.

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