Managing long-term risks

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The publication in 1972 of "The Limits to Growth" by the Club of Rome marked the emergence of a public awareness about collective perils associated to the sustainability of our development. Since then, citizens and politicians were confronted to a never ending list of environmental problems: nuclear wastes, genetically modified organisms, climate change, biodiversity, … This debate has recently culminated with the publication of three reports. On one side, the Copenhagen Consensus (Lomborg (2004)) put top priority to public programs yielding immediate benefits (fighting malaria and AIDS, improving water supply,...), and rejected the idea to invest much in the prevention of global warming. On the other side, the Stern Review (Stern (2007)) and the fourth report of the IPPC (IPCC (2008)) put a tremendous pressure for acting quickly and heavily against global warming. The absence of consensus among the experts on this question is translated in the public debate and in the public actions, notably with the patent failure of the Kyoto protocol.

A striking aspect of the recent debate on the climate change is the transfer of the hottest scientific challenges from the so-called hard sciences (climatology, oceanography, chemistry,…) to social sciences, and more specifically to economics. Still, the economic community is much divided on the way to approach long-term environmental risks. The absence of consensus about the efficient public policy for the environment may be explained by several factors. First, for many of the underlying long term environmental risks, there is still a lot of scientific uncertainty about their intensity and their impact on the welfare of future generations. Moreover, people have heterogeneous beliefs about the probabilities of really catastrophic consequences of various environmental policies. Second, based on these uncertainties, people disagree about whether we should wait or not to get better information before implementing strong actions. Third, there is much disagreement about how much effort should be done to improve the environment available for future generations. The bottom line is that there is no agreed-upon rule to evaluate long-term environmental risks and therefore no consensus about how to shape the environmental policy.

Recent advances have been made to provide a unified scientific framework to evaluate and to make policy recommendations for collective long-term risks. These progresses put a new light on concepts such as "sustainable development" and "precautionary principle" into efficient guidelines for collective decision making. Howard Kunreuther numerous works on the management of low or ambiguous probability to incur an extreme event have been instrumental to the emergence of these new insights.

The state-of-the-art methodology to evaluate an environmental project is based on the benefit-cost analysis in which the net present value of the future monetarized benefits is compared to the cost of the project. This is what is done for example in the case the reduction of emissions of carbon dioxide, in which the cost of reducing the emission of CO2 by 1 ton (through the substitution of fossil fuel by nuclear or solar technologies for example) is compared to the discounted value of the flow of future marginal damages generated by one more ton of CO2 in the atmosphere, the so-called "carbon value". Two crucial elements explain the very diverse estimations of this carbon value: the choice of the discount rate and the uncertainty

about the damages. Similar attempts to evaluate environmental policy in favour of the biodiversity, or of the moratorium on genetically modified organisms for example, led to similar ambiguous conclusions.

The consequence of these facts is an inefficient allocation of our resources invested for the future. Its cause, i.e. the missing consensual methodology, originates itself from a unified theory to evaluate long-term risks. Economists disagree on the rate at which one should discount far distant environmental benefits, on the way to take into account of uncertainties, or on the way to optimize the distribution of preventive costs over time. Today, the judge, the citizen, the politician and the entrepreneur are concerned by environmental problems, but they don't have a strong scientific basis for decision-making.

1. *The problem of discounting the distant future*

Let me consider the Stern Review on climate change as an illustration of the points I want to make here. Most critics about the Stern Review are related to the discount rate, which was fixed to 1.4% per year in the Review. It asserts that most of the consequences of global warming will not appear before the year 2100. Thus, not we but the future generations will bear the costs stemming from global warming. A crucial question, then, is to determine how much current generations should be ready to pay to reduce these future costs. We all agree that one euro obtained immediately is better than one euro obtained next year, mostly because of the positive return we can get by investing this euro. This arbitrage argument implies that costs and benefits occurring in the future should be discounted at a rate equal to the rate of return of capital over the corresponding period.

Because it is hard to predict the rate of return of capital for several centuries, one should follow an alternative approach to select the discount rate, which consists in evaluating explicitly the welfare effect of the environmental policy under consideration for each future generation. Because it compares consumption paths in which costs are redistributed across generations, it is important to make explicit the ethical and economic assumptions on which these comparisons were made. Most environmental policies will generate winners and losers, but economists evaluate the welfare gain by defining an intergenerational welfare function which is a (discounted) sum of the welfare of each generation.

The welfare approach to discounting is based on the additional assumption that future generations will be richer than current ones. In a nutshell, one should not be ready to pay one euro to reduce the loss borne by future generations by one euro, given that these future generations will be so much wealthier than us. Suppose that the real growth rate of the world GDP per capita will be 2% per year over the next 200 years, as was the case over the last two centuries in the western world, which implies that people will enjoy a real GDP/cap 50 times larger in 2200 than it is today. Suppose also that, as in the Stern Review in which the representative agent has a logarithmic utility function, doubling the GDP per capita halves the marginal utility of wealth. Combining these two assumptions implies that one more unit of consumption now has a marginal impact on social welfare that is 50 times larger than the same increment of consumption in 2200. This wealth effect corresponds to a discount rate of 2% per year. More generally, the so-called Ramsey rule states that the socially efficient discount rate is the product of the real growth rate of consumption by the elasticity of the marginal utility of consumption. The Ramsey rule, and its underlying wealth effect, is the cornerstone element in the current debate about the discount rate.

I am sure that Howard Kunreuther will agree with me that it is absolute non-sense to justify discounting the future on this argument without taking into account the enormous uncertainty affecting the long-term growth of our economy. Estimating the growth rate for the coming year is already a difficult task. No doubt, any estimation of growth for the next century/millennium is subject to potentially enormous errors. The history of the western world before the industrial revolution is full of important economic slumps (invasion of the roman empire, Black Death, worldwide wars,…). Some will argue that the effects of the improvements in information technology have yet to be realized, and the world faces a period of more rapid growth. On the contrary, those who emphasize the effects of natural resource scarcity will see lower growth rates in the future. Some even suggest a negative growth of the GNP per head in the future, due to the deterioration of the environment, population growth and decreasing returns to scale. They claim that the wealth effect goes the other direction, so that everything should be made to improve the future. This uncertainty at least casts some doubt on the relevance of the wealth effect to justify the use of a large discount rate.

We see here that the choice of the discount rate is one of the key elements in the definition of the notion of sustainable development, exactly as the interest rate is the key economic variable for economic growth. If we are very uncertain about the sustainability of our development, it would be good to reduce the discount rate – in particular the rate to discount distant cash-flows – in order to induce more investment for the (distant) future.

It is thus crucial to put growth uncertainty into the picture. This is required for the sake of realism, and it is essential if one wants to provide a credible economic approach to the notion of sustainable development. Instrumental to the standard analysis is the concept of prudence which refers to the consumer's willingness to save more in the face of an increase in his future income risk. Technically, an agent is prudent if the third derivative of his utility function is positive. Macroeconomists have been measuring the precautionary saving motive, and this literature tells us much about how much more sacrifices do people do when their own future becomes more uncertain. This well-documented observation justifies selecting a smaller social discount rate, implying more investments for the future. As explained by Gollier (2002), the benefits of these investments should be targeted for the time horizons with the largest uncertainty, ceteris paribus. This provides an argument for implementing a decreasing term structure of the discount rate, if this precautionary effect dominates the wealth effect for longer time horizons.

The existing literature is based on a completely standard expected utility modelling, where the welfare of each future generation is evaluated by computing their expected utility based on a probability distribution for the GDP/cap that they will enjoy. An important difficulty is that these probability distributions are ambiguous, in the sense that they are not based on scientific arguments, or on a data base large enough to make them completely objective. In a word, more than one stochastic process is compatible with the existing current knowledge to describe economic growth. The Ellsberg paradox tells us that most human beings are averse to ambiguity, which means that they tend to overweight the worse probability distribution when they compute their subjective expected utility. This suggests that agents systematically violate Savage's "Sure Thing Principle". More precisely, it seems that how we evaluate uncertain prospects depends on how precise our information about the underlying probabilities are - as opposed to the linearity of expected utilities in beliefs. Hence, a natural question to ask is, given ambiguity aversion, does a standard subjective utility model systematically under- (or over-) estimate the socially efficient discount rate?

As clearly explained in Hogarth and Kunreuther (1989), Kunreuther, Hogarth, and Meszaros, (1993), and Kunreuther, Meszaros, Hogarth, and Spranca (1995), introducing ambiguity aversion into the picture of the discount rate is crucial if one wants to have evaluation tools that are compatible with social welfare. It is also appealing as a normative concept to transform the precautionary principle into an operational rule that distorts collective beliefs in a pessimistic way. The degree of ambiguity aversion will determine the intensity of the pessimistic bias in the socially efficient collective evaluation of uncertain prospects compared to their objective equivalent risky prospect. The problem is that we don't have any clear indication of the degree of ambiguity to apply in the calibration of our evolution models.

2. *The problem of dynamic risk management*

Most environmental projects have uncertain future benefits. For example, according to the Stern Review, the best estimate for losses in the year 2200 is 13.8% of GDP, with a 90% interval of confidence that the true loss will be between 2.9% and 35.2% of GDP. Because future generations are risk-averse, the certainty-equivalent loss is larger than 13.8%. In practice, with the notable exception of the Stern Review, most evaluations of environmental policies are made by assuming risk neutrality, which tends to underestimate the value of risk prevention.

The state-of-the-art methodology is either to use an expected utility approach with an appropriate degree of risk aversion to compute certainty-equivalent benefits of preventive actions, or to use an asset pricing model from the theory of finance. This should be combined with the use of option values attached to more flexible dynamic strategies. However, this general methodology fails to take into account of important aspects of the economic problems, as we explain now.

- *Ambiguous benefits, small probability events and the precautionary principle*: In many circumstances, it is difficult to assess the precise probability distribution to describe the uncertainty faced by a decision maker, as is the case for most environmental policies, as those associated to global warming, or genetically modified organisms. Again, Howard Kunreuther will agree that the problem of imprecise probability is particularly crucial for very unlikely events, for which the speed at which one can learn from the empirical frequency is small. We must recognize that, because people are ambiguity-averse, the ambiguity on the distribution of impacts has an adverse effect on social welfare. What are the consequences of ambiguity aversion on the optimal investment in prevention? The general idea is that ambiguity aversion reinforces risk aversion to make people more reluctant to undergo ambiguous risky acts. The same idea can be found in the debate on the precautionary principle. This principle, which appears in various international texts as in the Conference of Rio on Environment and Development or the Maastricht Treaty. It states that "*lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation*". This principle has widely been interpreted as a recommendation for reducing the collective risk exposure in the presence of ambiguous probabilities. In short, ambiguity aversion should make us behave in a more risk-averse way. It has frequently been used in Europe against genetically modified organisms, or for an increase in the effort to reduce emissions of greenhouse gases.

- *Fat tails:* Robert Barro (2006) has recently claimed that the existence of "fat tails", i.e. small probability catastrophic events, plays a key role in the risk evaluation, and that the often assumed (log-) normality of the probability distribution is misleading. Martin Weitzman (2008b) shows that fat tails of the subjective beliefs occur in particular in a Bayesian framework with an uncertain variance.

- *The value of flexibility, the debate between mitigation and adaptation, and the energy problem*: In a risky environment, new information usually generates new decisions. But what can be done ex post affects the optimal action ex ante. In the context of climate change, there is an important debate emerging on the interaction between mitigation and adaptation to global changes. The optimal mitigation strategy depends on our beliefs about our Society's ability to adapt itself to changes to its environment. Moreover, new information about the intensity of the impacts of climate change, our about the availability of cheap technologies to limit emissions, affects the optimal mitigation strategy, and this flexibility should be taken into account to determine our optimal effort today.

  The emergence of the energy question in the public debate and the reduction of the stock of non-renewable resources raise similar policy questions. What is the optimal speed of resource extraction when the stock of the resource is unknown, or when the evolution of the cost of renewable energy sources is stochastic (Dasgupta and Stiglitz (1981))?

  What is the effect of flexibility on the optimal risk attitude. One need to compare the choices under risk in two different contexts. In the flexible context, the decision maker first selects a risk position in a choice set, and then takes an action after observing the risk outcome. In the rigid context, the agent must commit on an action before observing the state of nature. The intuition suggests that the agent should be more risk-prone in the flexible context than in the rigid one. This point is related to the irreversibility effect and real option values first developed by Henry (1974). However, the irreversibility effect is about the strategic preservation of more flexibility for the future, not about the risk attitude itself. As explained by Drèze and Modigliani (1972), the intuition that flexibility enhances risk tolerance is based on the well-known result that, in the flexible context, the value of information is always non-negative. It implies that the certainty equivalent of any lottery is larger in the flexible context than in the rigid one. If the choice problem is to choose between a risky prospect or a risk free prospect, any lottery that is acceptable in the rigid context is also acceptable in the flexible one. However, the enlargement of the lottery acceptance set due to flexibility does not mean that risk aversion is globally reduced.

  The value of flexibility and its consequence on the collective risk attitude is often overlooked in environmental economics. For example, in the Stern Review, it is implicitly assumed that all decisions about the mitigation of climate change should be made immediately. One need to approach the climate change problem and the energy problem by solving it via stochastic dynamic calculus, as in continuous-time finance with predictable assets returns (Merton (1969) and Samuelson (1969)). There are indeed clear links with the literature of dynamic finance: preserving a non-renewable resource, or reducing emission of CO2 under a constraint of maximum concentration is equivalent to an increase in saving; the uncertainty about the stock of the resource, or the uncertainty about the desirable maximum concentration of CO2 is parallel to

income uncertainty in the standard consumption-portfolio problem; emitting greenhouse gases when the environmental impact is uncertain is equivalent to investing in a risky asset. However, an important difference is due to the absence of an objective probability distribution for the impacts of climate change, or for the speed of technological progress.

- *Economics and psychology of the precautionary principle*: The normative theory of the efficiency of long-term environmental risks is based on standard assumptions: expected utility (possibly generalized to smooth ambiguity aversion), rational expectation, and exponential discounting of future felicity. This theory has a strong normative basis (the independence axiom for example), but a relatively weak positive power to predict real behaviours. Recent developments at the frontier between psychology and economics have revealed that people often evaluate, behave and judge other agents' decisions under uncertainty in a different way than predicted by the standard theory. Howard Kunreuther's research provides new insights for a better understanding of individual behaviours in the face of long-term, low probability, large consequence risks.

  An important aspect of the political economy of the precautionary principle is related to the way do people evaluate and judge ex ante collective decisions after new information is obtained about the risk. From a normative point of view, information non available at the time of the decision should be irrelevant to evaluate the optimality of the initial decision in the face of uncertainty. In reality, people have difficulties to behave in that way. For example, they usually feel regret (Bell (1982), Loomes and Sugden (1982)). Regret is a psychological reaction to making a wrong decision, where the quality of decision is predicated on the basis of actual outcomes rather than on the information available at the time of the decision. How does the aversion to regret affect the optimal level of prevention of a future risk? How do people weight the two types of regret/error (1. investing a lot in the reduction of CO2 emissions before learning that the economy can easily adapt to climate changes, and 2. not doing anything in mitigation before learning that the economy is badly hit by the increased temperature)? How do public decision makers react to the expectation that they will be judged by regret-sensitive agents?

  Another promising direction of research is related to the formation of beliefs about long-term risks, following our initial work in Brunnermeier, Gollier and Parker (2007). If people have anticipatory feelings about the future, they may want to distort their beliefs in order to fight their anxiety. In the above mentioned paper, this willingness to bias beliefs is limited by knowing that too much optimism or wishful thinking yield bad risk management for the future. We want to explore an alternative explanation based on the fact that too much optimism ex ante increases the chance of disappointment ex post. We will characterize the optimal distortion of individual and collective beliefs, and the equilibrium collective level of prevention of the risk (as a function of the duration between the decision and the realization of the risk).

These theoretical questions are at the heart of the debate on the evaluation and management of climate change. Up to now, most economists specialized on climate change focused their attention on the production of Integrated Assessment Models that combine a climate module and an impact module, with a relatively crude approach to risk evaluation, except IAMs developed by William Nordhaus, or more recently by Nicholas Stern. The extraordinary vivid

debate that followed the publication of the Stern Review at the fall of 2006 was mostly concentrated around the treatment of risk and time. The prospect that much progress will be done in the next few year is considerable. As witnessed by the path-breaking career of Howard Kunreuther, a not so much irrational economist, this will take place at the boundary of different disciplines: Psychology, sociology, political science, neuroscience, and economics.

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