Looking for a guide to protect the environment: the development of the Precautionary Principle

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Abstract

If the precautionary principle must become the guide of the international community for environmental protection policies, an economic interpretation of the principle is in order. The analysis of case studies and a survey of the recent decision theoretic literature show on the one hand, the difficulty of applying the principle due to the vagueness of the law and, on the other, the lack of a completely satisfactory economic modeling. More generally various theoretic and empirical results demonstrate that the precautionary principle cannot be assumed to apply *a priori*. The precautionary principle, proposed by international treaties as a rule of thumb to be used in situations of scientific uncertainty, could indeed be inefficient.

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Non-technical Abstract

The precautionary principle, the tenth of the great principles established at the summit of Rio and then emerging in the Maastricht Treaty, states that: "the absence of certainty, given our current scientific knowledge, should not delay the use of measures preventing a risk of large and irreversible damage to the environment, at an acceptable cost". Economists have always recognized the influence of inadequate information about human affairs, giving rise to an accepted theory of uncertainty and information. A common feature of all the examples we treat is that uncertainty is resolved at least partially over time. One of the most important sources of uncertainty is due to our imperfect scientific knowledge. Just think of the scientific uncertainty that has accompanied AIDS, the greenhouse effect, low radiological exposures, genetically modified organisms (GMO), or the mad cow disease.

This new notion of precaution elicits numerous interesting questions about its precise content and reach, its implications for liability law and its economic interpretation. This paper aims at giving a contribution to a better understanding of the principle from an economic point of view, leaving a more comprehensive analysis for further studies.

If we really want the precautionary principle to become the guide of the international community for environmental protection policies, an economic interpretation of the principle is in order. We survey the recent decision theoretic literature on the subject, showing that we still lack a widely accepted economic interpretation.

The analysis of case studies and a survey of the recent decision theoretic literature show on the one hand, the difficulty of applying the principle due to the vagueness of the law and, on the other, the lack of a completely satisfactory economic modeling. More generally various theoretic and empirical results demonstrate that the precautionary principle cannot be assumed to apply *a priori*. The precautionary principle, proposed by international treaties as a rule of thumb to be used in situations of scientific uncertainty, could indeed be inefficient.

1

Introduction

The high standard of living in most western countries relies heavily on large supplies of energy and raw materials. In recent years people have started worrying that the maintaining of this high standard could damage the environment. In the coming years the challenge will be to reconcile people's needs with environmental protection; this means promoting a sustainable growth path that satisfies the needs of the present generation without compromising the capacity of future generations to satisfy their own needs. Reconciling the environment and development was precisely the difficult task of the 1992 Rio summit on Earth. Developing countries accuse industrialized countries of overexploiting natural resources and compromising the world environment for their own comfort. The precautionary principle, the tenth of the great principles established at the summit of Rio and then emerging in the Maastricht Treaty, states that: "the absence of certainty, given our current scientific knowledge, should not delay the use of measures preventing a risk of large and irreversible damage to the environment, at an acceptable cost".

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This paper aims at giving a contribution to a better understanding of the principle from an economic point of view, leaving a more comprehensive analysis for further studies.

We survey the recent decision theoretic literature on the subject, showing that we still lack a widely accepted economic interpretation for the principle to become the guide of the international community for environmental protection policies.

How do we arrive at the notion of precaution? Chaumet and Ewald (1992) write:

> "Le XIX^e siècle avait inventé la prévoyance et en avait fait la principale des vertus. Le XX^e a remplacé la prévoyance par la prevention: prévoyance rendu obligatoire pour des raisons de sécurité sociale. Voici maintenant la précaution. Ce sont là trois attitude devant l'incertain. La prévoyance était liée à la notion de sort, de chance et de malchance; il s'agissait d'intégrer l'avenir dans le présent, mais à l'échelle de l'individu. L'assurance s'est longtemps présentée comme la science de la prévoyance...La prévention est une conduite rationelle

face à un mal que la science peut objectiver et mesurer. La prévoyance était contemporaine d'une ignorance des aléas de l'existence; la prévention se développe sur les certitudes de la science. Elle est la voie de la science qui impose de réduire les risques et leur probabilité. La prévention est l'affaire des experts certains de leurs savoirs. La précaution vise une autre nature de l'incertitude: l'incertitude des savoirs scientifiques eux-mêmes. Elle définit les conditions de la décision quand la seule certitude que l'on ait est que les savoirs, même les plus certains, sont ou seront controversés. Elle marque le passage d'une probabilité objective à une probabilité subjective, si caractéristique de la conscience que la science contemporaine a d'elle même."

The precautionary principle is therefore further reaching than the principle of prevention. While the latter commands the defence of the environment when it is possible to prove the harmful nature of the policy we are examining, the former only requires the presumption of possible damage. Precaution is the attitude following a dubious situation where some preventive measures seem to be necessary even if no certainty yet exists about the risks of the activity examined. Uncertain knowledge not only does not excuse but should induce a more prudent attitude. Aiming at reducing risks not yet identifiable must be implemented *ex ante.* As pointed out in the literature (Cameron and Wade-Gery (1995), Charlier (1998)), precaution is always preventive in some degree. However, measures preventing specific environmental damage can only be precautionary if they reduce the uncertainty of any other environmental losses to a greater extent than the established risk they prevent. The precautionary principle imposes certainly higher responsibilities on the decision makers, the risk is that too much responsibility being costly for companies could discourage them from taking risks. Therefore, if we really want the precautionary principle to become the guide of the international community for environmental protection policies, an economic interpretation of the principle is in order to understand what is meant by taking measures preventing a risk of large and irreversible damage to the environment, at an acceptable cost. The paper is organized as follows. Section 2 analyzes three case studies where the principle is relevant. Section 3 examines the idea of the recent literature to rationalize the precautionary principle through the existence of an irreversibility effect. Section 4 gives an alternative formal interpretation of the principle. Section 5 presents a non Bayesian approach to the principle. Section 6 concludes.

2 Some real-life examples

Our world is characterized by limited and uncertain knowledge. One of the most important sources of uncertainty is due to our imperfect scientific knowledge. Just think of the scientific uncertainty that has accompanied AIDS, the greenhouse effect, low radiological exposures, genetically modified organisms (GMO), or the mad cow disease. We present three case studies in an attempt to unveil the difficulty of understanding highly complex ecosystem interactions[1].

2.1 The mad cow disease case[2]

In the seventies the English cattle breeders started to feed their animals with flour made from animal carcasses improper for consumption, particularly sick rams. At the beginning of the eighties, exploiting a less restrictive law, the breeders adopted a less costly production procedure for the flour which reduced the heating stage used to kill the germs. In 1985 a new sickness called 'bovine spongiform encephalopathy'(BSE) is observed: the mad cow disease was born. The English government waited until 1988 before appointing a scientific commission to study the problem, and it put into practice only some of the recommendations of the commission, like banning flour made from the carcasses of sick animals. In its final conclusions in 1989, the commission declared that the transmission of BSE from bovines to human, although not scientifically excludable, was nevertheless highly improbable. The transmission of BSE from bovines to human is now considered more plausible in the scientific literature. In 1996, following 10 cases of deaths in humans, scientists considered that the most plausible explanation was the exposure of the victims to BSE. At that point the media took over the case and provoked in European consumers a reaction of suspicion toward bovine meat. Consumption fell by 30% to 40%, provoking an economic crisis in the breeding sector. In the mad cow disease case an important characteristic has been the lack of scientific knowledge. It took more than ten years from the identification of the first cases for this scientific ignorance about the causes and mechanisms of the sickness to be overcome. *Ex post* we can judge that it was a mistake on

[1] The interpretation of the principle and its application must be extended behond the environment to the all set of scientifically controversial risks of our society.

[2] The mad cow disease case is based on Jean-Jacques Duby's article: "L'affaire de la vache folle" (1996).

the part of the English government not to embark on a serious research program in 1985 or 1986 when BSE was rapidly developing in the stock farms. Ten years later, when the crisis exploded scientists did not know much more than before about the disease. This was thus a typical situation where the precautionary principle applies: the absence of certainty, given our current scientific knowledge and the risk of large and irreversible damage. What is less clear is whether the use of preventive measures had an 'acceptable cost'. An early research program was probably not too costly considering the huge cost of more recent preventive measures. The European embargo on English bovines is costing Great Britain 500 million pounds per year; and the plan to slaughter the animals approved by European Union is costing several billion pounds. Therefore, a first point is that an early application of the principle would probably have been less costly than this late one. A more difficult question is whether the enormous costs due to the late application of the principle can be considered acceptable. Certainly the main risk in this story is the transmission of the sickness to human beings, but what is not clear is if the risk is limited to the current frequency of some tens of deaths per year or if, as some scientists think, after a long-lasting incubation, there will be thousands of cases in the few next years. Let us turn now to a second case study.

2.2 Radiological risks[3]

The discovery of radioactivity dates from the end of the last century and was accompanied by the simultaneous development of radioprotection. The history of radioprotection is divided into two main phases. The first phase, was essentially concerned with the so-called deterministic effects. The name is due to its certain appearance after exposure to radiation of a given intensity. These effects, which had already been studied at the beginning of the history of radioactivity, appear when a given exposure threshold is exceeded; beyond the threshold the damage increases with the level of exposure. Between the 1920s and the 1950s, radioprotection was therefore essentially concerned with the setting of admissible levels of radiations at limits well below the thresholds known to trigger deterministic effects. This policy avoids the undesirable effects and is a clear application of the principle of prevention which

[3]The radiological risk case is based on Lochard and Shieber's article: "Gestion du risque radiologique: de la prévention à la précaution." (1997).

imposes intervention when the harmful nature of the policy we are examining is demonstrated. The second phase of radioprotection, during the second half of the century, corresponds to the development of military and industrial applications of nuclear energy and is characterized by the issue of the stochastic effects of radiations. These effects, which appear randomly among individuals in an exposed population, occur long after exposure. Stochastic effects are much more complex to face than deterministic effects: firstly, because it is impossible to predict who will develop the effects in an exposed population; secondly, we do not know if there is a threshold that triggers them. In 1958 the international commission for radiological protection officially recognize the existence of stochastic effects for levels of exposure below those triggering deterministic effects. In view of the impossibility of demonstrating the existence of a threshold that would certainly prevent stochastic effects, the commission implicitly based its recommendations on the precautionary principle, structuring radioprotection around the hypothesis that there is a risk at any level of exposure and that the risk increases in proportion to the total amount of exposure. Retrospectively, we recognize the adoption of the precautionary principle in the field of radioprotection, long before its adoption for many other risks. In effect, in the absence of certainty, the scientific community has adopted the prudent hypothesis of the absence of a threshold and of a proportionality between the level of exposure and the risk of stochastic effects.

2.3 Genetically modified organisms

One of the most fashionable examples of scientific uncertainty is the current controversy on genetically modified organisms. GMO are the object of conflict between the United States, which favors the commercialization of GMO, and Europe, which is more sceptical on the subject. As the debate is much more recent than those regarding BSE or radiological risks, there is still no agreement about the risks of the use of GMO and the costs of refusing them. The risks most frequently evoked concern human health (toxicity, possibility of allergies) and the environment (genetic mutations in animals fed with GMO, transfer of the gene to different cultures). Certainly, it is not in the best interest of the producers to underline possible dangers, and public research is thus necessary to avoid the mistake made by the British government of not initiating a serious research program in 1985 or 1986, when BSE was rapidly developing. In the absence of a clear answer to the existence or not of risks and assuming the need for further studies, an important factor is the economic aspect. What are the economic risks of the adoption of GMO technology? The development of biotechnologies could concentrate research on this single approach, leaving aside all other approaches (Bonny 1999a); the adoption of GMO could make farmers completely dependent on producers of GMO (Lepage 1999); it is often said that biotechnologies are indispensable to feed the world. GMO, which are essentially developed by private firms, are really aimed at solvent markets and not to help poor people: therefore, a real risk is that biotechnologies could worsen disparities by, for example, endangering mono-productions in many underdeveloped countries (Bonny 1998, 1999b); because of the ease of GMO dissemination, non GMO cultures could be contaminated by GMO cultures, and farmers might be unable to sell their biological production (Lepage 1999). What are the economic risks of the refusal of GMO technology? From a technical point of view the refusal could lead to the use of more pesticides or alternatively to more losses; a refusal would also reduce the possibilities of obtaining products suitable for many uses: foodstuffs, chemicals, pharmaceuticals or industrial goods; we could also fear that without the new depollution procedures offered by biotechnology the level of pollution will not go down; refusing GMO could also slow down progress in cellular biology and genetics due to the lack of economic incentives (Bonny 1999a). What would happen if Europe alone refuses GMO? There are various possible scenarios: if GMO are freely commercialized in Europe, it is reasonable to fear that the competition could be too harsh for European production, especially because production costs are often lower for GMO; if, on the contrary, the European Union bans GMO, this will certainly provoke trade conflicts that will have to be solved by the WTO. If Europe refuses GMO and if a non-GMO branch is developed, we wonder if this branch will be able to survive. In other words are there enough consumers interested in non-GMO products (Bonny 1999a)? Recently, the European Union ordered that GMO products should be subject to a compulsory label of the kind: "this product contains some GMO". For Europe this decision could be a compromise between simply refusing or accepting GMO. From our point of view this decision seems characterized by the shift of the right of applying the precautionary principle from Society as a whole to the individual. We think that labeling would be acceptable only if interpreted as part of a two step-process: firstly, Society should apply the principle controlling public research and evaluating if the absence of certainty, considering the costs of refusal and the risk of large and irreversible damage, imposes to ban

GMO or not; secondly, the individual will have to decide, given that public powers have accepted GMO, whether to bear the remaining risk, considering his subjective perception of this risk and his personal valuation of the cost.

3 Irreversibility and the Precautionary Principle

The idea presented in some recent papers by Gollier, Jullien and Treich (2000), Kolstad (1996) and Ulph and Ulph (1997) is to rationalize the precautionary principle by the existence of an irreversibility effect. An extensive literature has explored the effect of irreversibility constraints on decision-making. The idea is that decisions made today affect tomorrow's opportunity set. In this literature a decision-maker usually faces a first period decision variable which constrains the choice that must be taken in the second period. Arrow and Fisher (1974) and Henry (1974) establish the result that a risk-neutral agent should take stronger action to prevent future irreversible risks if he expects to obtain more information. Given an irreversibility constraint, present actions should be restricted to keep options open in the future. In the literature, this is called the 'quasi-option effect'. Freixas and Laffont (1984) generalize those results for a larger class of models including risk aversion. However, this level of generalization is still insufficient to rationalize the precautionary principle. The previous models assume intertemporal separability, i.e. the first period decision variable is not an argument of the second period utility function, it only affects tomorrow's opportunity set. Therefore, the choice results from an intertemporal trade-off between raising today's utility and constraining tomorrow's choices. In many environmental problems, there is a stock issue which generates intertemporal exernalities. In a sense, the first period decision is at the same time a quantitative and a qualitative one. The trade-off here is complex because each choice today also implies a different future payoff tomorrow.

The most general theory was developed by Epstein (1980), who provides necessary and sufficient conditions for the validity of the irreversibility effect. He finds that previous papers satisfy his sufficient condition for the irreversibility effect to hold, exactly because intertemporal separability of the objective function is assumed. Epstein's necessary and sufficient conditions are very general and are seldom useful to provide something operational for public policy. This is the reason why most recent contributions to climate change literature, although basing their theoretical support on Epstein's article, use numerical simulations, as in Kolstad (1996), Nordhaus (1994) and Ulph and Ulph (1997).

This last article points out the limits of the intertemporal separability hypothesis when climate change is considered as the result of the cumulative stock of greenhouse gases. It shows that in a model that includes these features Epstein's condition is not satisfied. Therefore, Epstein's result cannot predict whether or not the irreversibility effect holds in a model of global warming. Kolstad (1996) adds to Ulph and Ulph's irreversibility, linked to the cumulative stock of greenhouse gases, a second type of irreversibility coming from the sunk nature of the investment in emissions control and finds the same result.

Gollier, Jullien and Treich (2000) solve for the necessary and sufficient condition for a better information structure to decrease a first period decision variable with both risk-aversion and irreversibility. The appeal of this condition is that it imposes empirically testable restrictions on preferences. This is not the case in Epstein (1980).

In two related papers Pindyck (1991) and Dixit (1992) find evidence for the quasi-option effect, showing the existence of a positive option value for the strategy of delaying irreversible investment.

3.1 A general model[4]

Economists have always recognized the influence of inadequate information about human affairs, giving rise to an accepted theory of uncertainty and information. A common feature of all the examples we are treating is that uncertainty is resolved at least partially over time. Therefore, we will deal with dynamic models insisting on the fact that decisions are sensitive to the information available. Scientific uncertainty differs from risk mainly because of the possibility of diminishing over time. When we study the way uncertainty is resolved over time, we must consider the related information structure, i.e. a set of possible signals characterized by a statistical relation with the events we are interested in. The observation of this signal may change the beliefs in the events. The change in beliefs in turn has an impact on decision-making. To explain the notation and to recall the Bayesian

[4] This subsection relies on previous work by N. Treich (1997).

context let us write a general problem:

$$\max_{x_1 \in C_1} U(x_1) + E_y \max_{x_2 \in C_2(x_1)} E_{z|y} V(x_1, x_2, z) . \quad (1)$$

The random variable $\tilde{z}$ is discrete with n atoms $(z_1, z_2, ..., z_n)$. C_1 and $C_2(x_1)$ are convex subsets of the non negative real line with nonempty interiors. After deciding on x_1, but before the second period decision x_2, the realization of a random variable $\tilde{y}$, which is statistically related to $\tilde{z}$, is observed. The observation of this signal may change the beliefs on $\tilde{z}$. The change in beliefs in turn has an impact on the efficient level of x_1. We denote $\pi_y(z)$ the probability of $\tilde{z}$ conditional on the reception of the signal $\tilde{y}$, $\pi_y = (\pi_y(z_1), \pi_y(z_2), ..., \pi_y(z_n))$, and $S = \left\{ \pi_y \in R_+^n \, | \sum_{i=1}^n \pi_y(z_i) = 1 \right\}$ the set of potential conditional distribution on $\tilde{z}$. Utility functions U and V are assumed to be twice differentiable, with $U^{'} > 0, U^{"} < 0, V^{'} > 0, V^{"} < 0$.

There exist two equivalent representations of an information structure: one is characterized by the family of conditional distributions $p(y \mid z_i)$; an alternative representation is in terms of the posterior distribution of the underlying uncertainty given the particular observation of the signal $\tilde{y}$ and the marginal distribution of the signal $\tilde{y}$. Loosely speaking we will denote two information structures, y and $y^{'}$.

The information structure y is more informative than $y^{'}$[5] if and only if all expected utility maximizers observing y are as well off as when observing $y^{'}$. That is to say:

$$E_y \max_{x_2 \in C_2(x_1)} E_{z|y} V(x_1, x_2, z) \geq E_{y^{'}} \max_{x_2 \in C_2(x_1)} E_{z|y^{'}} V(x_1, x_2, z) , \quad (2)$$

for any x_1, any function V and any set $C_2(x_1)$ for which the maximum exists.

Later on Blackwell (1951) justified this definition from a statistical point of view. He patterned the definition of an information structure that is more informative than another on the concept of sufficiency. y is statistically *sufficient* for $y^{'}$ if, having observed the signal y, observing the signal $y^{'}$ add no further information.

Another definition due to Marschak and Miyasawa (1968) says that a signal y is more informative than a signal $y^{'}$ if and only if:

[5] Alternatively, y is a better information structure than $y^{'}$ or y is more precise than $y^{'}$.

$$for\ any\ \rho\ convex\ on\ S : E_y \rho(\pi_y) \geq E_{y'} \rho\left(\pi_{y'}\right). \quad (3)$$

As shown by Marschak and Miyasawa (1968), condition (3) is equivalent to the fact that all expected utility maximizers observing y are at least as well off as when observing $y^{'}$. To better understand (3) note that after observing the signal, the objective is

$$\rho(\pi_y) = \max_{x_2 \in C_2(x_1)} \sum_{i=1}^{n} V(x_1, x_2, z) \pi_y(z_i),$$

since expected utility is linear in the $\pi_y(z_i)' s$ ρ is convex.

Let us denote:

$$J(x_1, \pi_y) = \max_{x_2 \in C_2(x_1)} E_{z|y} V(x_1, x_2, z),$$

as the value function for the second period problem. Our goal is to measure the effect of a better information structure on the optimal choice of x_1.

3.2 Some results

Firstly, we recall the important result due to Epstein (1980), which provides a way to determine whether a better information structure increases or decreases x_1 for the following problem:

$$\max_{x_1} E_y J(x_1, \pi_y).$$

Theorem 1 *A better information structure decreases x_1 if and only if $J_{x_1}(x_1, \pi_y)$ is concave in π_y.*

This Theorem is very general and it imposes no restrictions. At the same time, being so general, it is seldom useful to provide anything operational. In fact, it is often difficult to verify concavity or convexity with respect to the vector of the conditional probability of the value function's derivative with respect to the parameter x_1.

Ulph and Ulph (1997) simplify the model in two directions. First, the nature of the information available: they consider the two extreme cases of No Learning versus Perfect Learning[6]; second, they consider separability

[6] This is a special case of the general model that allows the decision maker to receive a signal before period 2 which may not completely reveal the true state of the world.

in the second period between utility from consumption and the damage: $V(x_1, x_2, z) = W(x_2) - zD(\delta x_1 + x_2)$ with the constraints $x_1 \geq 0$, $x_2 \geq 0$. Variable x_t is the quantity of energy produced. It yields welfare but at the same time the stock of CO_2 generates climate changes. The economic cost of these changes is assumed to be proportional to the stock $X = \delta x_1 + x_2$ of CO_2. Parameter δ denotes the fraction of natural decay of CO_2. As a contribution to the theory they find an alternative (to Epstein's result) sufficient condition for the irreversibility effect to hold.

Theorem 2 *If in the case of no learning the irreversibility constraint bites, then the irreversibility effect must hold, i.e. first period emissions with learning will be no higher than first period emissions with no learning.*

Using a more general empirical model they show that for almost all parameter values the opposite of the irreversibility effect holds. Only in the case where there is a low discount rate and considerable uncertainty does the possibility of learning better information make a significant difference to current abatement of greenhouse gas emissions. Thus their paper demonstrates that in the case of global warming the precautionary principle cannot be assumed to apply *a priori.*

Kolstad (1996) introduces a stochastic, discrete time optimal growth model in the spirit of Ramsey to address the question of whether the stock nature of greenhouse gas emissions or the sunk nature of control costs leads to a bias in today's decisions regarding the control of greenhouse gases. Consistently with Ulph and Ulph he finds no evidence of a stock effect from greenhouse gases affecting today's control decisions. Only when emission control investment are very long-lived and irreversible is there a stock effect associated with control capital.

Gollier, Jullien and Treich (2000) find empirically testable restrictions on preferences for the following simple version of problem (1):

$$\max_{x_1} U(x_1) + E_y \max_{x_2 \geq 0} E_{z|y} V(x_2 - z(\delta x_1 + x_2)).$$

They find the following result:

Theorem 3 *Expecting more precise information regarding the risk of global warming reduces the current efficient emission of carbon dioxide if absolute* *prudence is larger than twice the absolute aversion to risk* $(P \geq 2A)^7$*, and if either the preferences are of the harmonic absolute risk aversion type (HARA) or the risk is binary. These conditions are necessary in the sense that if they are not fulfilled, then one can find a prior distribution of the risk and a better information structure such that the latter increases the efficient emission of greenhouse gas.*

This result shifts the problem of the validity of the precautionary principle to that of the empirical validity of the previous restrictions on preferences.

4 Self-Insurance versus Self-Protection

As defined by Ehrlich and Becker (1972) there are two methods for reducing the expected financial impact of a loss: reducing the probabilities of suffering losses (self-protection), and reducing the severity of a loss (self-insurance). They show that self-protection and market insurance can be both substitutes and complements. Dionne and Eeckhoudt (1985) show that a more risk averse agent does not necessarily invest more in self-protection activities. These peculiarities were clarified by Briys and Schlesinger (1990), who noted that self-protection does not trade income in one state of the world for income in another as market insurance does. But it rather reduces income in all states, shifting the support of the wealth distribution. This characteristic of self-protection makes its analysis quite difficult.

Gollier, Jullien and Treich (2000), Kolstad (1996), Ulph and Ulph (1997) noted that the intensity (rather than the probability) of potential losses could depend on the accumulation of earlier exposures to the risk. Therefore they emphasize the second method of reducing the expected financial impact of a loss, i.e., self-insurance. They find conditions in which when a better information structure on the distribution of the risks is expected a higher level of self-insurance (one consumes less) is efficient. This would be compatible with the precautionary principle.

In this section we present an alternative interpretation of the precautionary principle, due to Immordino (1998), requiring more self-protection rather than more self-insurance. The two approaches to the precautionary principle seem indeed to be complementary: the self-insurance approach is more suited

[7] Where $P(.) = -\frac{V'''(.)}{V''(.)}$ and $A(.) = -\frac{V''(.)}{V'(.)}$.

to cases such as the greenhouse effect, whereas the self-protection approach better describes other scientific uncertainties. By limiting dangerous behaviors or eating less beef, one actually lowers the probability of getting AIDS or mad cow disease, not their intensity.

4.1 Some results with self-protection

Immordino (1998) uses the following model:

$$\max_{x_1 \geq 0} U(w_1 - x_1) + E_{\tilde{y}} \max_{x_2 \geq x_1} p((\delta - 1)x_1 + x_2) E_{\tilde{z}|\tilde{y}} V(w_2 - \tilde{z} + x_1 - x_2)$$
$$+ (1 - p((\delta - 1)x_1 + x_2)) V(w_2 + x_1 - x_2)$$

In the first period the agent chooses the amount of investment in self-protection, x_1. In the second period he decides how much more to invest in self-protection (x_2) given the new information. We allow for the possibility that an early investment in self-protection is more effective than a late investment, i.e., $\delta \geq 1$. $p(.)$ the probability of getting a disease or suffering damage is assumed differentiable with $p'(.) < 0$. The rest of the model included the information structure is as in the previous section.

He finds the following result:

Theorem 4 *With risk-neutrality or with constant absolute risk aversion (CARA) preferences a better information structure decreases early investment in self-protection.*

The model shows that if we interpret the precautionary principle as requiring more self-protection today, it is difficult to accept it on efficiency grounds. As for the self-insurance interpretation of Gollier and others we need severe restrictions on preferences to get results. Eeckhoudt, Gollier, and Immordino (1999) in their health economics application show that rational patients perfectly informed about their health risks may choose to reduce their investment in self-protection when efficient diagnostic tests become available. At time 0, the patient is healthy and may undertake a preventive investment with the objective of reducing the probability of occurrence of a potential illness that may appear at "old age" (time 1). If illness occurs at time 1 a treatment strategy will be available. Its effects however are uncertain because if some side conditions are present the treatment will possibly have a negative impact on health. If the side conditions are not present, the treatment will have a perfectly known positive effect. They simplify the model in two ways: first, the patient's utility function in each period is additive in two arguments: wealth (W) and health (H) i.e. $V = V_1(W) + V_2(H)$;

Second they consider the following possibilities about diagnostic technology:

a) either it is expected that between time 0 and time 1 a perfect diagnostic test will be available to ascertain the presence or absence of the side conditions;

b) or it is expected that no such test will ever be available before time 1. They show that:

Theorem 5 *if case a prevails all risk averse decision makers will do less self-protection than in case b.*

Finally, Calzolari and Immordino (2000) study the international trade of goods subject to scientific uncertainty about their effect on consumers' health and which are at the center of international trade disputes[8]. They show that a new trade protectionism may arise because of scientific uncertainty. Their model is closer in spirit to the self-protection approach given that the consumption of the new product is characterized by a probability of being harmful. Their setting differs from the previous literature because the risk-neutral decision makers (the governments) act strategically. In this setting, if governments adapt their choices to the precautionary principle they will ban consumption more often if more information is expected in the future. In fact they show that scientific uncertainty pushes toward more conservative decisions today if the effects of consumption on health are long-lasting.

Theorem 6 *Going from no information to perfect information it is impossible to accept the innovative good for a country that used to ban it.*

In other words scientific uncertainty can become an informational barrier to trade. In their seminal works Arrow and Fisher (1974) and Henry (1974) establish the result that a risk-neutral agent should take stronger action to prevent future irreversible risks if he expects to obtain better information. Calzolari and Immordino (2000) showed that this result extend to a setting where decision makers act strategically.

[8]Consider for example GMO, the meat of animals fed with hormones, chicken carcasses washed with chloridric solution, and so on.

5 Some alternative approaches

In sections 3 and 4 we surveyed the branch of the decision theoretic literature that views scientific uncertainty as differing from risk mainly because of the possibility of diminishing over time and has adopted a Bayesian framework for the formal interpretation of the principle. Of course we must not forget that risk deals with objective probabilities while some of the uncertainty about critical issues in science is subjective. The Bayesian strand of the literature assumes the existence of probabilities and an information process based on Bayes rule. Bouglet and Vergnaud (1999) reconsider those problems assuming that the decision maker disposes of a family of probability distributions instead of a single one. They use Gilboa and Schmeidler (1989) max-min criterion of expected utility calculated on the family of probabilities. In this framework more information will reduce the 'ambiguity'. Formally this ambiguity reduction sums to a shrinking of the family of probabilities we started with (see Gilboa and Schmeidler (1993)). Bouglet and Vergnaud (1999) propose two types of models. The former treats the intertemporal separability studied by Arrow and Fisher (1974), Henry (1974) and Freixas and Laffont (1984). The latter considers the accumulation process typical of those models without intertemporal separability, focusing on the model of Ulph and Ulph (1997). Their results are similar to those in the Bayesian literature although there are important quantitative differences. The max-min criterion does not lead necessarily to more precaution than the Bayesian approach and there is no probability distribution that could produce exactly the max-min decisions.

Besides the diatribe between expected utility and non-unique prior (or the very much related non-additive probability approach), there is an open question ignored by both theories: the list of states of the world is given exogenously. In a situation of scientific uncertainty, considering all the possible states of the world is often impossible, and if feasible could be very costly. A distinction has been made between variables whose relevance the decision maker is aware of and those which he is unaware of (Dekel, Lipman and Rustichini (1998), Modica and Rustichini (1994, 1999)). "Being aware of the relevance of the facts in a set means having an idea of their interaction,...Becoming aware of new facts is forming an idea about their interaction with those already in the picture..."(Modica 1999). Choice with unforeseen contingencies, or choice with unawareness and 'awareness of unawareness' could generate some kind of preference for flexibility. This concept of 'awareness of unawareness' is not completely settled, but some work on preference for flexibility is motivated by this intuition (Rustichini (1998)).

6 Conclusion

If we really want the precautionary principle to become the guide of the international community for environmental protection policies, an economic interpretation of the principle is in order. The analysis of case studies and a survey of the recent decision theoretic literature show, on the one hand, the difficulty of applying the principle due to the vagueness of the law especially in view of the imprecise notion of the 'acceptable economic cost', and on the other, the lack of a completely satisfactory economic modeling.

More generally many theoretic and empirical results demonstrate that the precautionary principle cannot be assumed to apply *a priori*. The precautionary principle, proposed by international treaties as a rule of thumb to be used in situations of scientific uncertainty, could indeed be inefficient.

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