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Institutions and the Precautionary Principle: the Case of Mad Cow Disease

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Abstract - In the presence of scientific uncertainty many actions may end up in a catastrophic event. Many argue that in such cases the *precautionary principle* should be adopted. Unfortunately this principle is not clear-cut. The main purpose of this paper is to set up a model, which allows establishing the determinants and consequently the level of the precautionary acceptable cost. The model allows treating in a single framework ambiguity, catastrophic events and agency problem. The acceptable cost will be essentially determined as the amount of transfers or subsidy that the public body should direct to the agents in order to elicit the level of effort which - on the basis of the principal's most pessimistic forecasts - has the higher chances of maximizing the principal welfare and preventing the catastrophic event. The model refers to the BSE epidemic but it could be easily applied to other situations in which Knightian uncertainty (ambiguity) makes catastrophic events quite likely.

Keywords: ambiguity, agency, capacity, precautionary principle.

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Introduction

Uncertainty poses a hard challenge to economic theory and the design of efficient institutions. Scientific uncertainty about the consequences of human actions has recently engaged the attention of many scholars, especially economists. Actions with uncertain consequences may lead to catastrophic events. Global warming, AIDS, genetically modified organisms (GMO) and bovine spongiform encephalopathy - new-variant of Creutzfeldt-Jakob disease (BSE-vCJD) are notorious examples.

Which institutions and rules one must resort to in these cases it is unclear. Some argue that the state must step in and take an active role through regulations and prohibitions; others maintain that the state should merely supply information (mainly through labeling) leaving the freedom of choice to individuals.

Without entering the debate, it is evident that by adhering to the so-called *precautionary principle*, originally formulated with reference to environmental risks, many international institutions - most prominent among them the European Commission - do actually reject the minimalist position on state involvement. Unfortunately, this principle can be interpreted in different ways.[1] At least two different approaches can be distinguished. The first approach does not make any reference to the *ex ante* cost of precaution, more or less explicitly advocating safety, whatever the cost. The second approach recognizes that the costs of precaution are part of the principle itself; precaution cannot be defined without reference to the *ex ante* costs involved. The latter approach seems to be the one chosen by the European Commission. Indeed, in the Maastricht Treaty it is stated that uncertainty about the future is no reason for omitting any measure, which could prevent severe irreversible damage to the environment, provided that the cost of such measure is acceptable.

It is clear that the subject in charge of the measures aimed at preventing the risk of a large damage may be no one else but a public body. What an *acceptable cost* of precaution is and how can it be determined it is much less clear.

The main purpose of this paper is to set up a model apt to establish the determinants and the level of acceptable precautionary cost. Our model refers to the BSE epidemic but may be generalized to other situations in which Knightian uncertainty (ambiguity) could be associated with catastrophic events. The model enables ambiguity, catastrophic events and agency to be treated in a single framework. The agency problem is the conflict which normally arises when the consequences

[1] For an introduction to the precaution principle see, among others, Rao (2002, ch. 3). Different analytical approaches can be found, among others, in Chisholm and Clarke (1993), Gollier et al (2000), Immordino (2000), Perrings (1995), Taylor (1991)

of actions do not affect the agents entitled to decide about these actions - in other words, when the catastrophic event is an externality. The acceptable cost is essentially determined as the amount of transfers or subsidy that the public body should direct to the agents in order to elicit a level of effort consonant with maximizing the principal welfare and preventing the catastrophic event. There are good reasons for believing that transfers were far below what could be considered an acceptable cost in the institutional settings of the years preceding the outbreak of the BSE epidemic.

The paper is organized as follows. Bovine spongiform encephalopathy - new-variant of Creutzfeldt-Jakob disease are described and evaluated in Section 2. Section 3 examines the relationship between ambiguity, precautionary policy and economic incentives. Section 4 describes the model and its solutions. Section 5 regards the relationship between ambiguity and the precautionary principle. Section 6 contains concluding remarks.

2. Mad cow disease: evidence and costs

At a first glance the BSE epidemic, also known as *mad cow disease*, appears to be a modern plague spreading throughout the European Union (EU). It has led to massive slaughter of cattle, the collapse of the beef industry and an agricultural crisis.

The BSE disease appears to follow the standard scheme of an outbreak. The first signs were identified in the UK in 1985 (the famous case of the 'cow 133') and a year later the disease was officially recognized as an entity. In 1987 meat and bone meal were identified as the only plausible cause of BSE and the UK government announced a slaughter policy for animals showing BSE symptoms (1988). The peak of slaughtering was reached in 1993 with more than one hundred thousand confirmed cases of BSE. In 1996 the European Commission imposed a worldwide ban on UK beef export. In the same year panic ran rife in the EU when the Health Secretary Stephen Dorrell announced a probable link between the cattle disease and a human disease (a new variant of Creutzfeldt-Jakob disease). In the UK, 99 people, mostly young, died of an unfamiliar form of CJD and a further seven are still alive. There have also been nine deaths in the EU. All this is evidence that the disease has crossed the species barrier. In 2000, two events increased fear: a cluster of vCJD cases around the village of Queniborough in Leicestershire (UK) and the case of an infected baby girl born to a mother with vCJD.[2]

Scrapie has been endemic in England since the mid-1700s. It is a transmissible spongiform encephalopathy (TSE) found in sheep and goats, but strains have been found in elk, mule deer, white-tailed deer, mink and cats. Scrapie was regarded as a purely genetic disease until an infectious agent was identified. All forms of TSE, including CJD, attack and destroy the nervous system of the host organism. TSE is a progressive and incurable disease. No one knows precisely how the pathogenic agent infects the host. The disease is characterized by vacuolization of neurons in the brain, giving the brain the appearance of a sponge.

Each form of TSE is caused by a distinct variant of prion. Prions are rough proteins without nucleic acid (RNA or DNA), consisting of a single molecule of about 250 amino acids. They are different from virus and bacteria because they do not multiply by replication of DNA. Prions cause folding of normal proteins by direct contact. Scientists know little about dose effects and what initiates the conversion of normal proteins into prions. The agent of TSE multiplies slowly in the host, even for decades, and the immune system is not activated before the disease manifests itself. Unlikely conventional CJD, which was described in 1926, the variant associated with BSE is slower (up to 30 years to manifest) and seems more virulent in children. Epidemiological research shows that BSE originates from scrapie and vCJD from BSE, demonstrating that the species barrier can be crossed.

Scientists believe that BSE was caused by scrapie infected manufactured feedstock. Cattle feed has been produced from render animal protein since the 1930s. In the 1970s, a new procedure was introduced in the rendering industry with changes in processing time, temperature (below 165°C), batch versus continuous processing, and the use of hydrocarbon solvents to extract fat from meat and bone meal (MBM). Since animal protein feedstock contained at least 14% of sheep tissue, it is estimated that as many as 500000 contaminated beef carcasses entered the human food chain. At present 4.6 million cattle have been slaughtered in the UK and selective slaughtering has been ordered worldwide as a consequence of MBM export.[3]

Cattle, diary, agricultural, medical and health care industries have suffered collapse and huge losses. There is no single comprehensive quantification of the economic and financial cost of the BSE crisis in the UK; however, the following figures are a guide

[2] Because all aspects of transmission of the disease are not understood, the members of Spongiform Encephalopathy Advisory Committee (SEAC), a committee set up to help the British government manage the BSE-vCJD crisis, predict a rise from the current death toll of about 100 to136000.

[3] The British epidemic of BSE has affected more than 180000 cattle and has spread over the Continent. More than 1900 cases were reported in the EU, particularly in France, Ireland, Portugal but also in Spain, Italy and Germany. The UK stopped exporting of MBM for cattle feed in 1996.

Exchequer cost of BSE, 1996/97 - 2001/02: aid to producers, abattoirs, rendering costs, incineration, storage etc.	£4.6b (about 45% is reimbursed to the UK by the EU)

Lost value of beef exports, 1995:	£520m
beef 274000 head	£79m
live cattle and calves (calves 450000 head)	
	£599m

Other resource costs, 1996/97: includes fall in value of UK beef, loss of value of by-products, extra costs of regulation etc	£740m - 980m

NFU estimates (January 2000) of BSE-related costs to UK agriculture	£m pa
Loss of value of over 30 months old cattle	94
Loss of value of animal products (1996) (formerly used for MBM, tallow etc)	100
Cost of collection and disposal of SRM	11
Cost of collection and disposal of animal by-products	115
Cost of SRM inspections (deferred until 31 March 2004)	(20)
Cost of alternative feed (alternative to MBM in pig and poultry sectors)	30
Other administrative costs (removing sheep spinal cord, other control costs)	-
	£350m

Source: National Farmers' Union of England and Wales - BSE Briefing - Livestock Department, October 2000.

As a result of the BSE outbreak, the value of a finished steer weighing 500 Kg is currently £440 compared to £634 in 1995, implying that the average beef and sheep producer in UK earned £2400 per year (1998/1999) compared to £11800 in 1995 (pre-BSE level). UK agriculture has been in a serious recession for about five years. From 1995 to 2000 total agricultural income fell from £5.3 billion to £1.9 billion (- 64%) and the agricultural labor force lost more than 51000 people. In the year 2000 agriculture contributed 0.8% of the GNP and employed 557000 people (2.0% of the UK workforce).

It is also difficult to estimate the cost of BSE for related industries (drug, cosmetic, tourism), but rough evaluations talk about hundreds of millions a year.

3. Ambiguous events, economic incentives and coordination

From an economic point of view, the BSE epidemic is a tricky and complex case. It involves several different theoretical aspects. It is a standard example of an uncertain and irreversible event. Irreversibility breaks the temporal symmetry between the past and the future. The intuitive concept of irreversibility as a technological or physical constraint can be generalized to include irreversibility as a sunk cost. Uncertainty means that the consequences of economic decisions cannot be fully determined ex ante and all the uncontrolled variables of the decision process are random variables, which only depend on the possible state of nature that will occur in the future.

Savage expected utility theory (SEU), which is the standard approach to decision under uncertainty, assumes that future states of nature have an additive probability of occurring, that is, the individual's description of states of the world is exhaustive (Knightian risk). The individual has a unique probability distribution over events and exhibits an expected utility function linear in probability (*probability sophisticated expected utility maximizers*). Nevertheless, the phenomenon of ambiguity exists and manifests itself when the individual faces incomplete (*vague*) knowledge about the states of the world, as in the cases of BSE or the production of GMO.

In these cases the individual faces misspecified decision models. A description of the world may be considered a misspecified model whenever omitted states are not explicitly included. Due to ambiguity (Knightian uncertainty), the individual can represent her beliefs by a non-necessarily-additive measure or a set of additive probability distributions over events.[4] In the BSE epidemic, there was ambiguity about the link between scrapie and BSE, and between BSE and vCJD. There is still ambiguity about the link between eating mechanically recovered meat (MRM), which is used in

[4] Gilboa and Schmeidler (1989).

hamburgers and sausages[5], and contracting vCJD. On the other hand, the BSE outbreak and the vCJD epidemic are risky events induced by disease jumping in species barrier.

BSE is a multilateral, nodepletable externality produced by livestock; it has the characteristic of a public bad. It appears to be a textbook case: agents who generate homogeneous externality are distinct from those who experience it. Due to multilateral and nondepletable characteristics, the introduction of a standard market for the public bad does not lead to an optimal solution. The negative multilateral externality induces free-rider problems, makes the Lindahl solution very unlikely and could determine nonconvexity of outcome function. All these aspects prevent centralized or decentralized bargaining, making room for government use of subsidies, even if they can generate multiple local social optima.[6]

The BSE epidemic involves informational asymmetries and adverse selection. There is asymmetric information and adverse selection among agents (rendering and feed producer, rancher, butcher and consumer) in the beef chain. There is asymmetric information and adverse selection between feed industry and cattle firm (domestic or foreign).

The BSE outbreak can be seen as a principal-agent problem that involves hidden action. MBM and rendered products of cow and sheep carcasses were produced and labeled as feed for hogs, chickens and other farm animals and continued to be exported to many countries. In 1996, when it became clear that this meal had been fed to cows and sheep, the UK banned animal protein in feed and stopped exports of MBM. There is hidden action because butchers do not know whatever ranchers have fed cattle with animal protein.

Finally, the BSE epidemic brings to light the unquestionable failure of EU production subsidies in agriculture (common agricultural policy – CAP). The EU provides pounds-per-ton production subsidy but there is evidence that use of animal protein in feed was boosted by the high cost of plant proteins (soybean and alfalfa) and slumping of the farmer's percentage of raw price. In the food chain, processors and retailers put pressure on farm-gate prices, causing a vicious circle. Retailers cut farm-gate prices, farmers react by increasing production of output and when this fails, they cut costs, possibly at the expense of food safety and animal welfare. Partial compensation for slaughter was introduced in the UK in 1988; full compensation did not come until 1990. CAP subsidies are paid in Euro and their value was reduced by the strength of the pound; the indemnity gap of 75000 UK farmers was only partially bridged by the UK government.

[5] MRM is scraped and blasted from a carcass with high-pressure water jets after the better cuts of meat have been removed and could include spinal cord and other risky material. SEAC chairman Prof. Peter Smith said in a BBC radio interview "One would guess that this cheap meat product could have gone in school dinners and other large institutions" (Wall Street Journal August 10-11, 2001).

[6] Baumol and Oates (1988).

4. Model and Policy

On the basis of the analysis in the above sections, we model TSE as a principal-agent problem with hidden action under ambiguity.[7]

Social welfare depends on livestock quality (meat quality) which at least partially depends on using animal or plant proteins in feedstock. Since the government (*principal*) is unable to observe the quality of feed used by farmers (*agent*) there is a case of *moral hazard*. The government is interested in maximizing welfare and proposes a contract designating a rancher compensation scheme. The compensation scheme should incentivate the agent to take the fair feedstock (*action*). For the simplicity's sake, only two feedstock types are considered: animal and plant proteins. The former (animal proteins) denotes *low effort*, the latter (plant proteins) *high effort*. That is, the quality of the feedstock is the one-dimensional measure of the agent activity. Nonetheless, rancher effort is not observable by the principal, nor can it be inferred from the outcome. Therefore, the principal's welfare is stochastically related to the agent's effort by means of a conditional density function.

The principal faces ambiguity about the relationship between the type of feedstock and the BSE-vCJD epidemic. She is ambiguity averse, in other words she is pessimistic about the existence of a relationship between feeding and a transmission of disease from animals to humans. It is assumed that the government feels more confident that no outbreak will occur if the agent feeds cattle with plant proteins rather than animal proteins, but it is unable to attach a unique probability to contingent events: disease (BSE and/or vCJD) and no disease. The principal is characterized by an additive probability distribution that she regards as the best estimate and a set of additive probability distributions which are information consistent.**[8]** The principal is risk neutral but ambiguity-adverse maximizer interested in net welfare (principal's welfare minus farmer subsidy).

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[7] Our model has several features in common with the one developed in Mas-Colell, Whinston and Green (1995).

[8] Let S be a finite set of states of nature. An element $\sigma \in \Sigma = 2^S$ is an event, an action is a function $a: S \rightarrow \Delta(X)$, where $\Delta(X)$ is the set of lotteries on X., and let X be a finite set of consequences. Let $\{E_1, \ldots, E_n\}$ be a partition of S with reliable probabilities $p(E_i)$, such that $\sum_{i=1}^{n} p(E_i) = 1$, events in this partition are called *unambiguous*.

The set of information consistent additive probabilities is $\Pi(p) := \{\pi \in \Delta(S) \,|\, \sum_{s \in E_i} \pi(s) = p(E_i), i = 1, \ldots n\}$.

Moreover, for all $A \in S$ and for i=1,….,n , $\beta_i(A) = \{1$ if $E_i \subseteq$ A, 0 otherwise$\}$ be the function characterizing events including at least one unambiguous event (Eichberger and Kelsey 1999, p.118).

More specifically, the principal is an *E-capacity maximizer* with a *degree of confidence* $\rho\in[0,1]$.[9] If the information partition does not contain only single element sets and the degree of confidence ρ equals 1, there will be ambiguity about events but the principal will feel that her probability assessment is correct. If the degree of confidence ρ equals 0 the principal will attach a set of probability distributions over events, none of which will be considered fully reliable.

Let $w(q) = q$ be the principal welfare (risk-neutrality), with $q \in [q°, q^*]$ where q^* is high quality meat and $q°$ low quality (infected) meat. Let e be agent effort, where $e°$ is low effort and e^* high effort. Since effort is not observable, the relationship between the principal's welfare, that depends on quality q, and the agent's effort e, is described by a conditional density function $f(q|e)$, with $f(q|e)\geq 0$ for all e and $q \in [q°, q^*]$.

There is conflict between the targets of the principal and the purposes of the agent. First-order stochastic dominance is assumed for the cumulative distribution functions $F(q|e^*) \leq F(q|e°)$, for all $q \in [q°, q^*]$, with strict inequality for some q. This implies that the principal's expected welfare is larger with e^* than with $e°$.

The agent is a risk-averse utility maximizer and dislikes high effort. His separable utility function $u(s,e) = v(s) - g(e)$ depends on subsidy $s=s(q)$ and on his effort $g(e)$, where g represents effort disutility in money, and $g(e^*) > g(e°)$. The agent's utility increases with subsidies and decreases with the effort; moreover, $u(s,e°) > u(s,e^*)$ for all s.

The principal offers the rancher a contract in which the agent effort is specified and subsidies are defined as a function of quality $s(q)$. The farmer can accept or reject; in the latter case he receives no subsidy.

Given unobservable effort and ambiguity aversion, the optimal contract for the principal solves the following problem:

$$\mathrm{Max}_{s(q)} W(q,e) = \rho \int_{q°}^{q^*} (q - s(q)) f(q|e)\,dq + (1-\rho) \min_{s(q), f(q|e)} \int_{q°}^{q^*} (q - s(q)) f(q|e)\,dq \quad [1]$$

such that

[9] The E-capacity (Ellsberg capacity) represents the majority of preferences (ambiguity aversion) observed in the seminal thought experiment of Ellsberg (1961). Formally, *E-capacity* $\upsilon(\pi, \rho)$ with degree of confidence $\rho\in[0,1]$ is defined by $\upsilon(A|\pi,\rho) := \sum_{i=1}^{n} [\rho\pi(A \cap E_i) + (1-\rho) p(E_i)\beta_i(A)$ for all $A \subseteq S$ (Eichberger and Kelsey 1999, p.119).

$$(i)\int_{q^\circ}^{q^*} v(s(q))f(q|e)dq - g(e) \geq \bar{u}$$

$$(ii)\mathrm{Max}_{\bar{e}} \int_{q^\circ}^{q^*} v(s(q))f(q|\bar{e})dq - g(\bar{e})$$

The condition (*i*) is a *participation constraint*, requiring that the agent's expected utility at least equals his reservation utility level $\bar{u}$. The condition (*ii*) is an *incentive constraint* that assures the rancher's optimal effort *e*, under the compensation scheme *s*(*q*).

Since the contract specifies effort *e*, the principal has to minimize the expected value of subsidies by choosing *s*, in order to maximize [1]. That is

$$\mathrm{Max}_{s(q)}W(q,e) = \rho\int_{q^\circ}^{q^*} -s(q)f(q|e)dq + (1-\rho)\min_{s(q),f(q|e)} \int_{q^\circ}^{q^*} -s(q)f(q|e)dq \qquad [2]$$

or

$$\min_{s(q)} W(q,e) = \rho\int_{q^\circ}^{q^*} s(q)f(q|e)dq + (1-\rho)\max_{s(q),f(q|e)} \int_{q^\circ}^{q^*} s(q)f(q|e)dq \qquad [3]$$

such that

$$(i)\int_{q^\circ}^{q^*} v(s(q))f(q|e)dq - g(e) \geq \bar{u}$$

$$(ii)\mathrm{Max}_{\bar{e}} \int_{q^\circ}^{q^*} v(s(q))f(q|\bar{e})dq - g(\bar{e})$$

Let us consider the case in which the principal wants to induce effort *e**. Constraint (*ii*) can be written

$$(ii^*)\int_{q^\circ}^{q^*} v(s(q))f(q|e^*)dq - g(e^*) \geq \int_{q^\circ}^{q^*} v(s(q))f(q|e^\circ)dq - g(e^\circ) \qquad [4]$$

Given [2] and assuming that the co-state variables are strictly positive[10], *s*(*q*) must satisfy the first-order condition

$$\rho(-1)f(q|e^*) + (1-\rho)(-1)f^\wedge(q|e^*) + \lambda v'(s(q))f(q|e^*) + \mu v'(s(q))[f(q|e^*) - f(q|e^\circ)] = 0$$

where *f^(q|e)* is the minimum conditional density function with respect to e* in the informative consistent sets.

Dividing by *f(q/e*)v'(s(q))*, first-order condition becomes

$$\rho(-\frac{1}{v'(s(q))}) + (1-\rho)(-\frac{1}{v'(s(q))}\frac{f^\wedge(q|e^*)}{f(q|e^*)}) + \lambda + \mu[1 - \frac{f(q|e^\circ)}{f(q|e^*)}] = 0 \qquad [5]$$

or

$$\frac{1}{v'(s(q))}[\rho+(1-\rho)\frac{f\wedge(q|e^*)}{f(q|e^*)}]=\lambda+\mu[1-\frac{f(q|e^\circ)}{f(q|e^*)}] \qquad [6]$$

To evaluate how the subsidy varies with ρ, consider the derivative of [6] with respect to ρ

$$\frac{1}{v'(s(q))}[1-\frac{f\wedge(q|e^*)}{f(q|e^*)}]=\lambda+\mu[1-\frac{f(q|e^\circ)}{f(q|e^*)}] \qquad [7]$$

and $\frac{1}{v'(s(q))}[1-\frac{f\wedge(q|e^*)}{f(q|e^*)}]\le(\ge)0$, in other words, subsidy may decrease or increase when ρ increases.

Consider the case of ρ=1, then $\frac{1}{v'(s(q))}=\lambda+\mu\left[1-\frac{f(q|e^\circ)}{f(q|e^*)}\right]$ [8]

This is the case in which the principal faces ambiguity but is certain about the correctness of her best probability assessment.[11] This is a special case of E-capacity in which there is only an additive conditional probability distribution. The compensation scheme pays more than in the case of observable effort[12] for outcomes that are statistically more likely to occur under e^* than under e° and less for outcomes that are statistically more likely under e° than under e^*.[13]

Consider the case of ρ=0, then $\frac{1}{v'(s(q))}\frac{f\wedge(q|e^*)}{f(q|e^*)}=\lambda+\mu[1-\frac{f(q|e^\circ)}{f(q|e^*)}]$ [9]

Divide by $\frac{f\wedge(q|e^*)}{f(q|e^*)}$ and obtain

$$\frac{1}{v'(s(q))}=\frac{f(q|e^*)}{f\wedge(q|e^*)}\{\lambda+\mu[1-\frac{f(q|e^\circ)}{f(q|e^*)}]\} \qquad [10]$$

Under ambiguity aversion, the optimal compensation is smaller (respectively larger) if $f\wedge(q|e^*)>f(q|e^*)$ (respectively $f\wedge(q|e^*)<f(q|e^*)$) with respect to the case of ambiguity being disregarded. Roughly speaking, under ambiguity aversion the principal pays less for bad outcomes, that are more likely with $f\wedge(q|e^*)$ than with $f(q|e^*)$ and pays more for good outcomes that are more likely with $f(q|e^*)$ than with $f\wedge(q|e^*)$.

Consider the case in which the principal implements e°. The principal offers a fixed subsidy

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[10] Zero valued co-state variables are either impossible or imply violation of constraints.
[11] If the informative set only includes singletons there is no ambiguity and the degree of confidence does not matter.
[12] When effort is observable, the optimal compensation scheme is $\frac{1}{v'(s(q))}=\lambda$, payment is a constant and the farmer receives exactly his reservation utility level, that is $v(\bar{s}(q))-g(e)=\bar{u}$
[13] Respectively, $\left[\frac{f(q|e^\circ)}{f(q|e^*)}\right]<1$ and $\left[\frac{f(q|e^\circ)}{f(q|e^*)}\right]>1$

$$s^{\circ} = v^{-1}[\bar{u} + g(\bar{e})] \qquad [11]$$

whether or not ambiguity is considered. Since the agent's subsidy is unaffected by the level of effort, he always chooses e°, that is the effort with the lowest disutility, and always receives $\bar{u}$.

This framework shows that the principal induces effort on the basis of her expected net welfare. Due to ambiguity, the more pessimistic probabilities may alter the expected welfare attached by the principal to different q and this in turn implies that in order to maximize welfare the principal will associate higher or lower subsidies with the various observed results, according to the criterion specified above. In fact, e^* can always be induced by sufficiently high subsidies at outcomes very likely to occur when high effort is chosen. Obviously, the subsidy function must fulfill the agent's incentive and utility constraints. This effect of ambiguity can be labeled the *welfare effect* on the subsidies. Alongside this effect, another can be singled out. We shall call it the *higher effort inducing effect*. It takes place when ambiguity makes it worth implementing higher effort, whereas without ambiguity lower effort maximizes the principal's net welfare.

5. Ambiguity and the precautionary principle

The precautionary principle is generally regarded as the most useful guide for behavior in the face of scientific uncertainty and when the risk of catastrophic events is non negligible. It became notorious after the 1992 UN Conference on the Environment in Rio de Janeiro, when it was put forward as the tenth of the great principles agreed on in the Conference. Indeed, the principle was already embodied in international law. At Rio the principle was stated in the following words:

"Where there are threats of serious or irreversible damage, lack of scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation".

As it stands, this version of the precautionary principle seems to originate from the preoccupation that scientific ignorance may justify a dangerous inertia in the field of environmental policies. In more recent times other perspectives have been adopted, and sometimes the principle has been advocated to caution against the risks of "doing too much" (in particular in the realm of scientific research) rather "doing too little".

Irrespective of this, there is an almost general agreement among commentators that the precautionary principle - in the Rio formulation or any other proposed since – is very hard to implement because of its vagueness.

A much debated question in this respect is the role that costs (or, to be more precise, acceptable costs, as the EU calls them) have to play. A sharp distinction can be drawn on the basis of the reference to the ex ante costs implied by its implementation. Some do not mention these costs at all, whereas other relate the precaution principle to the evaluation of costs it implies. We have already mentioned that the Maastricht Treaty, which makes reference to the acceptable cost of precaution, belongs to the latter type of approach.

The model we worked out implies that it is not safe to assume that safety is worth any ex ante cost, and goes in the direction of defining and determining precautionary acceptable cost, which is a thorny question.

It is fairly obvious in our model that the cost is acceptable if it maximizes the ex ante welfare of the principal - in our model this cost is the subsidy paid to the agent. As the model shows, the subsidy changes according to how pessimistic the attitude of the principal is towards the probability of catastrophic events.

Actually, it is difficult to approach the problem in terms of costs without also taking benefits into account. In other words, the problem is whether and how to use cost-benefit analysis (CBA) with respect to the precautionary principle. In our opinion there is no doubt that costs and benefits have to be explicitly considered when applying the principle. The troubling questions are which costs, which benefits; and whose assessment is to be taken as the basis for calculation?

The latter question highlights a crucial and often neglected problem in the interpretation of this principle. The presence of scientific uncertainty makes it impossible to refer to ordinary risk assessment: different people hold different probability distributions and the same people have more than one probability distribution. The outcome of CBA is therefore extremely sensitive to which (and whose) probability distribution we rely on.

Indeed this is an institutional problem with deep distributive implications, in terms of income and welfare. The distributive nature of the precautionary principle has been aptly emphasized in Geistfeld (2001).

Our model makes the point quite clear and suggests a solution to the problem. The principal-agent framework underlines that the institutional setting has to be sufficiently specified to single out who is the principal in any situation. The principal has the right to impose her evaluation of expected costs and benefits on whoever plays the role of agent and pursues goals which may conflict with the principal's.

Another aspect of our model is of particular relevance to the implementation of the precautionary principle: the principal has to behave on the basis of her most pessimistic probability distribution. This seems to be a straightforward implication of the precautionary principle. What else could precaution mean but behaving on the basis of the most pessimistic expectation?

In conclusion, by modeling scientific uncertainty as a principal-agent problem in the presence of ambiguity, the two most serious obstacles to the implementation of the precautionary principle can be easily singled out, as well as some reasonable solutions to them. It is worth stressing that institutional and distributive matters do play a crucial role.

A final remark is in order. As we have seen, the 'efficient' contract may be extremely complex and not easy to write down. The difficulty is largely due to the fact that the subsidy depends on the principal's assessment of the probabilities of various outcomes. The contract is therefore likely to be burdened by a high degree of ambiguity, which is a well known source of transaction costs. Ambiguity in the evaluation of uncertain events may transform itself into ambiguity in the writing of contracts. This is another crucial institutional aspect of the problem.

6. Concluding Remarks

Our model treats scientific ignorance as ambiguity and makes it possible to determine the behavior of a rational, ambiguity-averse principal with respect to the incentive to be paid to the agent whose actions can cause a catastrophic event. The main results of the model have already been summarized together with its implications for the much-cited precaution principle, adoption of which is advocated by many under scientific ignorance. The most serious obstacles to implementation of the principle can be traced to institutional and distributive difficulties.

It is fairly obvious in our model that the cost is acceptable if it maximizes the ex ante welfare of the principal on the basis of the latter's most pessimistic probability distribution. In our model this cost is the subsidy paid to the agent that varies according to how the principal is about the probabilities of catastrophic events. We explained that two effects may be at work here: the effort inducing effect and the welfare maximizing effect. The implications for the precautionary principle and its acceptable cost are straightforward:

Acceptable costs of precaution are equal to subsidies to be paid to the agent in order to elicit the higher effort under the most pessimistic assumptions of the principal on the possibility of catastrophic events.

This principle has been violated in several respects in the BSE case. By any realistic standard, the probability of the catastrophe was not the most pessimistic. As a consequence of this and also because of underestimation of the damage associated with the catastrophe (sketched in the preceding pages), the cost that public bodies representing societies paid for precaution was too low – much too low, we dare say - to act in a rationally precautionary way and prevent the catastrophic events which are taking place.

Another interesting case in this respect is the Japanese mad cow disease crisis in 2001. Despite warnings from the EU about the possibility of the disease spreading to Japan, the Japanese Ministry of Health refused to bolster the country's BSE surveillance system and only made a recommendation against MBM. In the fall of 2001, after the first case of domestic BSE, the Japanese officials announced a plan to test every slaughtered cow for BSE, even though the tests do not detect the disease in young animals and at least 5000 cows (estimation) had been fed a MBM. If a ban on MBM is too drastic a measure, given uncertainty and the possibility of consumer panic, an incentive against use of MBM would be better than an ineffective recommendation.

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