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The Paradox of Precaution

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The Paradox of Precaution*

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Résumé / ***Abstract***

Aux États-Unis et dans la plupart des pays industrialisés, les règlements et politiques publics relatifs à la sécurité alimentaire, la santé au travail et la protection de l'environnement sont en principe basés sur l'information émanant des scientifiques. L'accélération et la complexité du progrès technologique rendent toutefois inévitable pour le régulateur de devoir prendre des décisions avant que la science puisse fournir une représentation claire du risque. Dans ce contexte, l'approche dite du «Principe de précaution» recommande d'«errer du côté de la prévention» jusqu'à ce que les scientifiques puissent donner le ton juste. Nous produisons une représentation formelle de ce principe, et nous montrons qu'il contient une incohérence logique. Ce résultat négatif permet néanmoins de préciser le type d'actions que la réglementation des risques basée sur la science devrait promouvoir en présence d'incertitude scientifique.

Mots clés : Risques à la santé humaine et à l'environnement, réglementation basée sur la science, incertitude scientifique, principe de précaution.

In the United States and most industrialized countries, regulatory policies and decision-making pertaining to food safety, occupational health and environmental protection are science-based. The actual pace and complexity of technological innovation, however, make it increasingly necessary to deal with situations where science cannot yet provide a definite picture. In this context, a now widely invoked rule, known as the 'Precautionary Principle', recommends to 'err on the side of preservation' until better scientific information becomes available. We draw a formal representation of this statement, and we show that it exhibits a logical contradiction. This negative result conveys a clarification of the type of actions science-based regulation should consider in the presence of scientific uncertainty.

Keywords: *Environmental and health risks; science-based regulation; scientific uncertainty; Precautionary Principle.*

Codes JEL : K32, D70, D81.

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"When you doubt, abstain." - *Zoroaster*

I. Introduction

Science-based risk analysis is a fundamental input of regulations and public policies intended to protect human health and the environment. With the acceleration of technological innovation, however, governments are increasingly being called upon to address new or emerging risks and to manage issues where current scientific evidence is inconclusive. In such circumstances, a somewhat natural way to proceed - now referred to as the *Precautionary Principle* - is to 'play it safe' until scientists can provide a clearer picture.

As a formal rule for public policy and decision-making, the 'Precautionary Principle' first appeared as the *Vorsorgeprinzip* (literally, the "forecaring" principle) introduced into German environmental law in the early 1970s.[1] It has since been embedded in several laws and regulations of the European Union, such as the Ministerial Declaration on the Protection of the North Sea and the Maastricht Treaty. In international agreements and rulings, it can now be found in the United Nations Framework Convention on Climate Change, the Bamako Convention on Transboundary Hazardous Waste, the 1992 Rio Declaration, the Energy Charter Treaty, and the recent Cartagena Protocol on Biosafety. In a statement illustrative of what the Principle means, the International Joint Commission appointed under the U.S.-Canada Great Lakes Water Quality Agreement issued, in

[1] Precautionary measures to deal with danger have of course been applied for a long time. An oftentimes mentioned early example is the removal of the handle of the Broad Street water pump in London in 1854, an action that stopped an epidemic of cholera (see, e.g., Charles E. Rosenberg, 1962). This measure followed documented (but unconfirmed) suspicions by John Snow, a physician and much revered early epidemiologist, that the cause of the disease originated in the pump. (Afterwards, a detailed investigation determined that, more than 20 feet underground, a sewer pipe passed within a few feet of the well.)

1992, the following call to phase out all persistent toxic substances in the Great Lakes ecosystem:

> Such a strategy should recognize that all persistent toxic substances are dangerous to the environment, deleterious to the human condition, and can no longer be tolerated in the ecosystem, *whether or not unassailable scientific proof of acute or chronic damage is universally accepted*. [Emphasis added]

In the United States, many laws, regulations and statutes, such as the National Environmental Policy Act, the Clean Water Act, the Occupational Safety and Health Act, and the Federal Food, Drug, and Cosmetic Act, have a similar precautionary nature. The state of Massachussetts enacted a Precautionary Principle Act in 1997. The Federal Aviation Administration took a precautionary action when it banned use of cell phones and electronic devices at takeoff and landing, based on a single study that suggested these devices might interfere with a plane's electronic systems.[2] And the U.S. Food Safety System stipulates that "conservative" risk management decisions be implemented when safety information on a hazard in a food is "substantial but incomplete," a recommendation that was recently upheld by the prohibition of certain food or color additives, drugs and ruminant feeds in the aftermath of the bovine spongiform encephalopathy (or "mad-cow" disease) outbreak in Europe.[3]

Despite this widespread use, however, the Precautionary Principle remains controver-

[2] At the time, according to Nancy Myers and Carolyn Raffensperger (2001), scientists had not been able to duplicate that study.

[3] Contrary to a common belief holding that "Precaution is for Europeans" (*New York Times*, May 18, 2003), a closer look reveals that neither the U.S. nor the Europeans can claim to be systematically more precautionary. In fact, key differences in political systems, legal traditions and risk perceptions render the real pattern quite complex and risk-specific (see Jonathan B. Wiener and Michael D. Rogers, 2002).

sial and is often the object of acrimonious debates. Advocates argue that it provides potential victims a safeguard against sloppiness or manipulation in science-based regulation; but critics say that it gives undue veto powers to "environmental extremists" to block technological progress and opens the door to lobby groups to foster trade protectionism. Admittedly, in its present form the Precautionary Principle is a rather vague rule exposed to discordant interpretations.[4] The potentially high stakes involved would make a clarification of its meaning and use quite timely. Yet, aside from a few notable exceptions, economics has so far devoted little attention to this task.[5]

This note first investigates the internal consistency of the Precautionary Principle. We point out that all statements of the principle currently involve three key items: (1) some disagreement among scientists giving way to a range of undismissable scenarios, (2) collective preferences and beliefs that identify at least one of these scenarios as a plausible "bad", and (3) a feasible (i.e. morally acceptable, technologically doable, and affordable) precautionary strategy that, if implemented, would reinforce the status quo.

[4] Many books and articles discussing the interpretation and implementation of the precautionary principle have already been published. The following works would constitute a representative sample: David Appell (2001), Daniel Bodansky (1991), Kenneth R. Foster et al. (2000), David Freestone and Ellen Hey (1996), Olivier Godard (1997), I. M. Goklany (2001), John S. Gray and John M. Bewers (1996), Giovanni Immordino (1999), Myers and Raffensperger (2001), Tim O'Riordan and James Cameron (1994), Raffensperger and Joel Tickner (1999), and Alistair Scott et al. (1999).

[5] In a two-period model balancing the economic risk of immediate precaution versus that of possibly having to incur significantly harsher measures once scientific uncertainty dissipates, Christian Gollier et al. (2000) develop formal conditions on the regulator's utility function - namely, that the coefficient of absolute prudence be larger than twice the coefficient of absolute risk aversion - that would make her adopt the former strategy. This contribution, however, did not address the fact that conflicting scientific assessments create a situation of choice under *ambiguity* (i.e., where it is unknown which probability distribution actually represents the risk). Among recent papers dealing explicitly with this, Claude Henry and Marc Henry (2002) provide conditions on social preferences *and* on beliefs that would render nonprecautionary policies suboptimal, and Morgane Chevé and Ronan Congar (2002) show that invoking the precautionary principle amounts to deciding based on the maximum of minimum expected utility criterion developed earlier by Itzhak Gilboa and David Schmeidler (1989).

A formal representation of these elements is developed in the following section. Section III establishes that opting for (3) whenever (1) and (2) hold - which corresponds to what most statements of the Precautionary Principle actually say - entails a logical contradiction. This finding calls for a narrower and more precise definition of the Precautionary Principle. Some steps in this direction are taken in Section IV. Section V concludes the paper.

II. Axioms and Definitions

A representative statement of the Precautionary Principle would be the following one:[6]

> When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause-and-effect relationships are not fully established scientifically.

As already noted by several people (e.g., Raffensperger and Ticker, 1999), this rule rests essentially upon three components: "scientific uncertainty", "threat of harm", and "precautionary action". We will now give these items a formal representation. The first two are the *raison d'être* of the Precautionary Principle - without some perceived potential harm there would be little scope for precaution, and without scientific uncertainty standard risk management (as described, for instance, by Robert A. Pollak, 1995) would suffice - and they will be treated as axioms. The third one will be given a precise definition, which will in particular distinguish precautionary from preventive action.

[6] This statement emanates from a conference involving ecologists, policy makers, scientists and lawyers that took place in January 1998 at Wingspread, Wisconsin. [The book by Raffensperger and Ticker (1999) is a collection of the articles presented at this conference.] Other statements, like the ones figuring in the Rio Declaration or the Maastricht Treaty have opened the door to cost-benefit analysis, endorsing precautionary measures only when the expense is reasonable given the stakes and the level of protection that would be achieved. This qualification (and others), however, does not interfere with our main result, which assumes the availability of a *feasible* precautionary strategy.

A. *Scientific Uncertainty*

A common truism is that 'good' scientists can recognize 'good' science when they see it. This does not mean, however, that they would always endorse the same scientific conclusions. First, the systems investigated by health and environmental scientists are large and complex, often chaotic, and frequently not amenable to modelling or experimental manipulation. Hence, scientists have so far been unable to agree on the timing and regional impact of global warming, the assimilative capacity of the North Sea or the Great Lakes ecosystems, and the likelihood that genetically modified organisms (GMO) entail genetic mutations affecting humans. Second, sufficient data may also not be obtainable within a sensible time frame, if at all. The dioxin risk assessment initiated a decade ago by the U. S. Environmental Protection Agency, for example, has not yet succeeded in portraying somewhat accurately the impact of this chemical. Dioxin has sure been associated with cancer, chloracne, endometriosis, and other diseases, but contrary to the usual dose-response patterns it is both acutely and chronically toxic at very low doses. This raises the possibility that similar effects would occur at even lower, still unmeasurable, exposure levels. Were extensive data available, finally, substantial gaps and disagreements may remain. The possible health effects of radio frequency fields, for instance, have been studied since World War II, and there is an abundant literature on the subject. Yet, no scientific consensus has emerged that would answer public concerns that living near a power line or other electrical utility, or using a mobile phone, increase the risk of cancer.

In a formal sense, different, yet valid, scientific assessments can therefore produce different probability distributions. Discrepancies may arise when assessing the support of a distribution (as in the dioxin case) or the odds of a given outcome (as in the GMO example), or both (as in global warming). Such a situation is captured by the following axiom.

AXIOM 1: *Scientific assessments form a set of* $n \geq 2$ *Bernoulli distributions* $[\omega_0, \omega_1; q_1]$, $[\omega_0, \omega_2; q_2], ..., [\omega_0, \omega_n; q_n]$, *where* ω_0 *represents the current state of the world,* ω_i $(i = 1, ..., n)$ *denotes the state that may obtain if a given activity is pursued, and* q_i *is the corresponding probability that* ω_i *materializes (so* $1 - q_i$ *is the probability of remaining in the present state* ω_0*). These distributions are distinct in the sense that, for at least one pair* (i, j)*, we have that* $\omega_i \neq \omega_j$ *or* $q_i \neq q_j$ *.*

Hereafter, these distributions will sometimes be referred to as *scenarios.* Note that the ω_i's $(i = 0, 1, ..., n)$ could themselves be probability distributions, dynamic trajectories or stochastic processes, so there is little loss of generality in focusing specifically on Bernoulli distributions.[7] In the context of global warming, the axiom would say that experts agree on what the earth climates could be over the next century if the current stock of greenhouse gases in the atmosphere were to remain at current levels, but that at least two of them hold different assessments of the nature or the odds of climatic changes associated with the continued (or accelerating) atmospheric accumulation of such gases.

At this stage, however, there is no evaluation of the foreseen states of the world

[7] Mordecai Kurz (1994) has provided a compelling rationale for the persistence of disagreements among experts. According to a nice theorem of this paper, furthermore, rational beliefs (i.e., beliefs 'compatible' with the data, in a precise sense) can be represented as a convex combination of two (orthogonal) probability measures.

nor weighing of the alternative distributions. Science-based regulation separates risk assessment from risk management, so the appraisal of scientifically-established scenarios is not up to the scientists to deliver. This step is considered in the upcoming section.

B. *Threat of Harm*

As a rational risk manager and decision maker, the regulator may often rank public policies based on an expected utility criterion. This presupposes that some relative weights or beliefs are put on the supplied scenarios, and that the various states of the world are compared according to some utility index $u(\cdot)$. For the Precautionary Principle to be of interest, it must then be the case that at least one foreseen state of the world, say ω_1, would be worse than the current state ω_0. This is the content of a second axiom.

AXIOM 2: *The regulator evaluates public policies according to expected utility: (i) She puts a positive relative weight* α_i*, with* $\sum_{i=1}^{n}\alpha_i = 1$*, on each scenario* $i = 1, ..., n$*; (ii) She orders the various states of the world using a utility index* $u(\cdot)$ *such that* $u(\omega_1) \leq u(\omega_2) \leq ... \leq u(\omega_n)$ *and* $u(\omega_1) \leq u(\omega_0)$*.*

A weight α_i may represent the probability that scenario i is the correct one (in this framework, q_i would be interpreted as the conditional probability that ω_i occurs given that scenario i materializes). This number would then correspond to the acknowledged reputation of the scientists or the scientific methodology supporting scenario i, or be the outcome of public debates and represent, for instance, the proportion of stakeholders who find that scenario i is the most likely.

The use of an expected utility ranking to set public policy can be grounded on the 'Harsanyi doctrine' and on Harsanyi's Social Aggregation Theorem (see John Harsanyi, 1955, 1977). Admittedly, this complete ranking seems to assume away social controversies concerning, for instance, the credibility of science (as in the "mad-cow" disease crisis in Europe) and the evaluation of far-distant states of the world (as in public debates surrounding the consequences of global warming), which many see as central to any practical context where the Precautionary Principle applies. But note that the above axiom precisely allows for *any* utility index, however unsettled, as long as one of the scenarios is perceived as raising a potential threat.[8]

C. *Precautionary action*

In the context of the Precautionary Principle, precautionary actions are meant for 'erring on the side of preservation'; their primary goal is therefore to maintain the current state of the world (at least until scientific uncertainty dissipates). Certainly, phasing-out industrial chlorine chemistry in the Great Lakes region (as the International Joint Commission recommends), enforcing stringent limits on neighboring radio frequencies (as Italy and Switzerland respectively did in 1998 and 1999), banning beef imports from countries that have experienced only one case of bovine spongiform encephalopathy, and ruling to eliminate chrlorinated pesticides and polyvinyl chloride plastics - the largest sources of dioxin - would all qualify as valid examples of precautionary actions. But

[8] Dissension about the incidence and severity of potential harms could also give rise to significant political economy issues. Dealing with such issues is unfortunately beyond the scope of this paper.

milder strategies, such as providing incentives (e.g., through carbon taxes or subsidies to public transportation) to reduce the consumption of fossil fuel, would also fit the intuitive notion of precaution.

The latter example illustrates that, perhaps contrary to a common viewpoint, precaution does not necessarily stand for radicalism in the reduction of hazards. Certainly, a precautionary strategy must make the occurrence of some alternative state of the world less likely; but its key characteristic lies rather in its ability to achieve this under *more than one* scenario. Opting for precaution thus consists in implementing some generic or 'upstream' preventive measures (such as partial phaseouts and monitoring requirements) that do not specifically fit a particular framework, as opposed to taylored preventive actions or cures (like contaminants thresholds and industrial design specifications) which are meant to abate a well-defined risk. This meaning is conveyed by the following definition.

DEFINITION: *A precautionary strategy is a course of action which uniformly increases the probabilities of remaining in the current state of the world. Under such a strategy, the contemplated Bernoulli distributions would become* $[\omega_0, \omega_1; p_1], [\omega_0, \omega_2; p_2], ..., [\omega_0, \omega_n; p_n]$, *where* $p_1 \leq q_1$, $p_2 \leq q_2$, ... , $p_n \leq q_n$, *and* at least two *of these inequalities are* strict.

Most statements of the Precautionary Principle and a growing jurisprudence now impose some requirements on the available spectrum of precautionary actions.[9] These must first be morally acceptable, technologically doable and affordable. They must also be subject to reconsideration, following the evolution of science, technology and society.

[9] For further discussion, see Freestone and (1996), Godard (1997), O'Riordan and Cameron (1994), and Raffensperger and Tickner (1999).

They must compare to interventions that have been or would be made in similar circumstances. And they must introduce as few trade restrictions as possible. From now on, a precautionary strategy that satisfies these constraints will be called *feasible*.

III. An Impossibility Result

Drawing lessons from the "mad-cow" disease and other crises that still plague many countries, a regulator may find it legitimate to rely on precaution when science provides serious, yet mitigated, warnings of potentially dreadful and irreversible harm. The Precautionary Principle aims to articulate this approach further within current science-based regulations. Perhaps surprisingly, however, standard statements of the principle entail a paradox: the very context of precaution - scientific uncertainty and potential harm - does *not* necessarily entail the adoption of a given (even feasible) precautionary strategy. This is the main result of the paper.

THEOREM: *Suppose that there exists a feasible precautionary strategy. The statement that the regulator should implement this strategy whenever Axioms 1 and 2 are verified is inconsistent.*

PROOF: For $i = 1, ..., n$, denote $d_i = \alpha_i(q_i - p_i)$ and $\delta_i = u(\omega_i) - u(\omega_0)$; and let then $d = (d_1, d_2, ..., d_n)$ and $\delta^t = (\delta_1, \delta_2, ..., \delta_n)$.[10] Using this notation, Part (ii) of Axiom 2

[10] Here, δ is taken to be a column vector, so δ^t denotes its transposed.

holds if and only if $A\delta \leq 0$ where

$$A = \begin{pmatrix} 1 & 0 & 0 & ... & 0 & 0 \\ 1 & -1 & 0 & ... & 0 & 0 \\ 0 & 1 & -1 & ... & 0 & 0 \\ .. & .. & .. & .. & .. & .. \\ 0 & 0 & 0 & ... & 1 & -1 \end{pmatrix}$$

is an $n \times n$ matrix.

Now, suppose that whenever Axioms 1 and 2 are valid we also find that $d\delta = \alpha_1(q_1 - p_1)(u(\omega_1) - u(\omega_0)) + \; ... \; \alpha_n(q_n - p_n)(u(\omega_n) - u(\omega_0)) < 0$, so the regulator's objective is higher when the precautionary strategy is implemented. By Farkas's lemma (see, for instance, R. Tyrrel Rockafellar, 1970), there must then exist a row vector of nonnegative real numbers $k = (k_1, k_2, ..., k_n)$ such that $d = kA$, that is: $d_1 = k_1 + k_2$, $d_2 = k_3 - k_2$, ..., $d_n = -k_n$. Since all the d_i's are nonnegative, these numbers would furthermore satisfy

$$k_1 \geq -k_2 \geq \; ... \geq -k_n \geq 0 \; . \tag{1}$$

But the latter entails that $k_2 = k_3 = ... = k_n = 0$, and so $d_2 = d_3 = ... = d_n = 0$, which contradicts the definition of a precautionary strategy. Q.E.D.[11]

An economic intuition for this result would be the following. In the context set by

[11] One could have done without Farkas's lemma by simply noticing that, since the δ_i's can be positive for $i > 1$, the statement that $A\delta \leq 0$ implies that $d\delta < 0$ is valid only when the corresponding d_i's are themselves non positive. This argument, however, delivers little economic intuition.

Axioms 1 and 2, 'erring on the side of preservation' is justified up to the point where the marginal return on prevention under some scenario i, which is given by the decrease $d_i = \alpha_i(q_i - p_i)$ in the probability of leaving the status quo, equals the cost of potentially losing one more utile, which is given by a linear combination of the shadow prices k_i and k_{i+1} associated with the contraints on the utility difference $\delta_i = u(\omega_i) - u(\omega_0)$. If $i > 1$, however, a threat of losing some additional utiles means that $\delta_i \leq \delta_{i+1} - \varepsilon$ $(\varepsilon > 0)$ instead of $\delta_i \leq \delta_{i+1}$. This does not preclude any of the previous utility shifts (including, of course, the better ones). The shadow prices k_i and k_{i+1}, and so the marginal return d_i, must therefore be equal to 0 whenever $i \neq 1$. This henceforth rules out many preventive measures, in particular those relatively upstream and generic ones that characterize precaution. The upcoming section will now consider various ways to overcome this.

IV. Discussion

From the beginning, the Precautionary Principle has been challenged. Attempts at finding practical compromises have usually centered on putting further restrictions on the set of allowed precautionary actions. As our theorem shows, however, supposing that this approach would not render the whole principle vacuous - in the sense that no precautionary action would ever satisfy the added qualifications, it would still not answer suspicions that the Precautionary Principle is overall ambivalent and meaningless. Another way to deal with criticisms would now be to examine some departures from the above axioms.

First, consider Axiom 1. While scientific uncertainty cannot be ruled out, this axiom is not, of course, the only representation of it. One might think, for instance, that scientists would produce probability distributions of different types or avoid quantitative modelling altogether. Many qualitative descriptions and assessments do fit the Bernoulli framework, however, and there are compelling arguments supporting the use of Bernoulli distributions to model heterogenous beliefs (Kurz, 1994). One might also point out that scientists could disagree as well on the current state of the world. But such a situation would be one of *ignorance* rather than ambiguity, a feature that many scholars (for example Godard, 1997) locate beyond the scope of the Precautionary Principle, for it is in particular not clear what a recommendation to 'err on the side of preservation' would mean in this context.

Turning now to Axiom 2, the proof of our theorem first suggests to replace the expected utility criterion by the maximum of the minimum expected utility. This conclusion matches that of other formal analyses (e.g., Chevé and Congar, 2002). It runs contrary to the Harsanyi Doctrine, however; and in practice, it may exacerbate the dispute between advocates and opponents of cost-benefit analysis. The alternative is to introduce additional requirements on the utility index $u(\cdot)$, which amounts mathematically to inserting new lines in the matrix A. It can be checked that imposing that the function $u(\cdot)$ be concave (thereby exhibiting risk aversion) still leads to an impossibility result.[12] On the other hand, replacing $u(\omega_1) \leq u(\omega_0)$ by $u(\omega_i) \leq u(\omega_0)$ for some $i > 1$ does *not* entail a logical contradiction. This proviso simply authorizes precautionary actions that only

[12] To see this, note that the constraint $\delta_2 - \delta_1 \geq \delta_3 - \delta_2$ is a necessary condition for $u(\cdot)$ to be concave. Adding this constraint to Axiom 2 amounts to putting the extra line (1 -2 1 0...0) on top of the matrix A. Give this new line the number 0. Farkas's lemma now yields the inequalities $d_1 = k_0 + k_1 + k_2 \geq 0$, $d_2 = -2k_0 - k_2 + k_3 \geq 0$, $d_3 = k_0 - k_3 + k_4 \geq 0$, $-k_4 \geq ... \geq -k_n \geq 0$, where k_0 is the shadow price associated with line 0. The latter inequalities imply that $k_4 = ... = k_n = 0$, so $d_4 = ... = d_n = 0$, but also that $k_0 \geq k_3 \geq 2k_0 + k_2$, so $k_0 = k_2 = k_3 = 0$ and $d_3 = d_2 = 0$.

change the scenarios whose label is not greater than i.[13] A useful corollary of the theorem is now at hand.

COROLLARY: *Suppose that Axiom 2 is amended so that* $u(\omega_i) \leq u(\omega_0)$ for some $i \geq 1$. *A precautionary strategy that is consistent with Axioms 1 and 2 would increase the probability of remaining at the status quo under scenarios* $j = 1, ..., i$, *but it would leave the other scenarios unchanged.*

This finding raises the informational requirements to implementing a precautionary strategy: 'erring on the side of preservation' must be made conditional upon identifying not just one but several dangerous scenarios. It also conveys a formal version of the so-called 'proportionality' clauses which are often invoked to qualify the Precautionary Principle: the higher is the number of threatening scenarios, the more upstream (hence radical) precautionary strategies can be.

V. Conclusion

Science-based regulation must increasingly cope with situations where the input of science is ambiguous. A frequent approach in this context - known as the Precautionary Principle - stipulates that one should adopt sensible and generic preventive measures until scientific information becomes clearer. This paper introduced an intuitive formal version of this rule. Our main result, however, points out an inherent logical contradiction. The

[13] Postulating that $u(\omega_i) \leq u(\omega_0)$ amounts to moving the number 1 rightward, up to the i-th column, in the first line of the matrix A. For example, let $i = 2$. From Farkas's lemma, it follows that $d_1 = k_2 \geq 0$, $d_2 = k_1 + k_3 - k_2 \geq 0$, $-k_3 \geq ... \geq -k_n \geq 0$. This system does not preclude that d_2 *and* d_1 be positive.

practical upshot is that endorsing the Precautionary Principle makes sense provided the regulator either foregoes an expected utility ranking of policy alternatives, or confines the impact of precautionary measures to the hazardous scenarios. This represents one further step towards an operationalization of the Precautionary Principle.

The above exercise, however, must not overlook other important issues that the current framework does not address, such as the management of expertise and the consequent evolution of scientific knowledge, the political economy of environmental and safety regulation, and the shared burden of selecting and implementing precautionary strategies. Dealing with those issues as well is bound to deliver the analytical apparatus that science-based public policy making urgently needs.

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