THE OUTER BOUNDS OF THE POSSIBLE: ECONOMIC THEORY, PRECAUTION, AND DIOXIN

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Introduction

Exactly how bad for human health is dioxin? Decades of technical research have not brought closure to this crucial question, with fundamental disagreement continuing among the participants in the debate. The precautionary principle is designed for circumstances like this, calling for protective action even in the face of continuing uncertainty. But the principle often remains abstract. How does society decide what, if any, precautionary action to take?

A little-known but important economic theorem, co-authored by Nobel laureate Kenneth Arrow more than 30 years ago, demonstrates that in cases of great uncertainty, the most efficient approach to public policy is based solely on knowledge of the extreme outer bounds of the range of possible outcomes. Nothing is added by attempts to find the midpoint, average, or best point estimate, if the uncertainty is sufficiently great. This paper explores the application of such economic analyses to the dioxin debate, where the outer bounds of the possible imply two radically different pictures of environmental impacts.

In 1972 Kenneth Arrow and Leonid Hurwicz analyzed the problem of choice under conditions of "pure uncertainty," where no information is available about the probability of different possible outcomes.[1] Although they did not discuss the problem in terms of precaution, their analysis provides a useful framework for understanding and implementing the precautionary principle. Richard Woodward and Richard Bishop (whose treatment of the issue is the primary source for this discussion) presented a stylized example of pure uncertainty in public policy, which they call the "Expert Panel Problem."[2] A panel of experts, all of whom have in-depth knowledge of an issue, disagree about the expected outcome of alternative policies. All of the expert forecasts are known to be plausible, but nothing is known about which forecast is more probable. In the absence of any information about probabilities, the standard, expected-utility models of economics and probabilistic methods of risk assessment cannot be used to make a decision.

Formally speaking, Arrow and Hurwicz analyzed a finite, bounded set of options under conditions of pure uncertainty (where boundedness means that for each option there is a single best outcome, and a single worst outcome). They were interested in finding choice criteria, applicable to such a set of options, which meet several straightforward conditions of logical consistency. For example, removal of a suboptimal policy option should not influence the choice of the optimal policy. Perhaps most controversial was their assumption of the irrelevance of repetition: the desirability of a policy does not depend on how many times it is advocated. (If nothing is known about the probability that any one forecast is correct, then it doesn't matter how many members of the panel agree with a given position. Notice that the situation would be quite different if every expert were assumed equally likely to be correct; then repetitions of a view would be evidence in its favor.)

Arrow and Hurwicz found that any criterion consistent with these assumptions ranks policies solely on the basis of their best and/or worst possible outcomes. Rational decision-making under conditions of pure uncertainty, in other words, is based entirely on the outer bounds of the possible, not on midpoints, averages, or consensus forecasts of the most likely outcome.

Several different choice criteria satisfy the Arrow-Hurwicz assumptions: for instance, an optimist could form judgments based only on the best possible outcome for each policy, while a pessimist could rely only on the worst case. Subsequently, other analysts using similar assumptions have shown that if society is risk-averse, or prefers a diversity of options in the face of uncertainty, then the pessimist's decision rule is the only appropriate one to use.[3,4] That is, risk aversion or a desire for diversification should lead to adoption of the "maxmin" criterion: choose the policy option with the least harmful worst-case outcome – exactly as the precautionary principle would suggest.

The hypothesis of pure uncertainty and the framework of the expert panel problem, as described above, seem plausible as approximate characterizations of the ongoing debates over policy toward dioxin. There is a set of divergent expert estimates of the health impacts of dioxin, but there is nothing approaching agreement about the probabilities that should be attached to rival estimates. This paper illustrates the application of the Arrow-Hurwicz approach, and the maxmin criterion, to the issue of policies toward dioxin – both to outline an approach to dioxin, and to clarify the general meaning of these relatively abstract economic criteria for precautionary decision-making.

Methods and Materials

Identification of the range of expert opinion on dioxin was based on a review of EPA's Draft Dioxin Reassessment, combined with a selective review of recent academic publications on dioxin dose-response relationships. High and low estimates of the expected impacts of dioxin, drawn from this literature review, were initially expressed as pg/kg/day of lifetime exposure, per 1% excess cancer risk, and then arithmetically converted to µg/person/lifetime of exposure, per statistically expected excess cancer (assuming a linear no-threshold dose-response curve). All dioxin quantities are measured in grams on a TEQ_{DF}-WHO_{98} basis.

Emissions data and economic information were largely based on published sources, as described below. Beyond the published sources, several arbitrary assumptions were required to complete the economic calculations; notably, the calculations assume that half of all dioxin is due to the PVC lifecycle. Hence the numerical results remain illustrative, rather than definitive.

Results and Discussion

At the high end, several recent studies find that as little as 1 pg/kg/day of lifetime exposure to dioxin could lead to an excess cancer risk of about 1%.[5,6,7] At the low end, a significant number of participants in the recent EPA Science Advisory Board review of the Draft Dioxin Reassessment argued that there was no proof that dioxin is a human carcinogen.[8] Thus the low case is an estimate of zero cancer risk from dioxin.

The high-end estimate implies that 1% excess cancer risk is associated with a total lifetime exposure, for a 70 kg person, of

$$1 \text{ pg/kg/day} * 70 \text{ kg} * 365 \text{ days/year} * 75 \text{ years} = 1.92\ \mu g$$

Under the assumption of a linear no-threshold dose-response curve, one excess cancer would be expected, on average, from 100 times this quantity of lifetime exposure, or 192 µg. Equivalently, the number of excess cancers expected per gram of exposure would be 1/.000192 = 5220.

The Draft Dioxin Reassessment estimated average exposure to dioxin of 41 pg/day for adults (and very similar amounts, 36-43 pg/day depending on age, for children and adolescents; see the Reassessment, Part I, Volume 3, Chapter 4, Table 4-34 on p.4-115). [9] For the 285 million residents of the U.S. as of 2001, this implies a national total exposure of

$$(41*10^{-12}) \text{ g/person/day} * (285*10^{6}) \text{ people} * 365 \text{ days/year} = 4.27 \text{ grams/year}$$

(For the sake of comparison, note that this is equivalent to 0.14% of the 3125 grams of dioxin emissions to air in 1995, as reported in the Reassessment.) Thus the high-case estimate would imply 5220 cancers/gram of exposure * 4.27 grams = 22,300 cancers due to a single year's exposure. The low-case estimate, of course, is zero.

Under these assumptions, the economic theories presented above suggest that policies toward dioxin should be evaluated under the alternate hypotheses (1) that dioxin causes 22,300 cancers annually, and (2) that it does not cause cancer. Someone who accepts the high case might advocate a policy such as (A) eliminating all use of polyvinyl chloride (PVC), a material that has frequently been identified as a leading cause of dioxin formation in waste combustion and accidental fires.[10] Someone who accepts the low case might prefer a policy of (B) doing nothing.

The best case for policy (A) is hypothesis (1): if dioxin causes thousands of cancers annually, elimination of PVC prevents many of those cancers. The worst case for (A) is hypothesis (2): if dioxin does not cause cancer, elimination of PVC imposes needless economic costs on society. Conversely, the best case for policy (B) is (2): if dioxin does not cause cancer, doing nothing avoids any needless expenses. The worst case for (B) is (1): if dioxin causes many cancers, doing nothing allows many preventable cancers to occur.

Assuming that society is risk-averse in this area, economic theory tells us to choose the policy with the least harmful worst case. That is, the costs of PVC elimination, if it turns out to be unnecessary, should be weighed against the cancers that could have been prevented, if dioxin turns out to be highly carcinogenic. Additional illustrative calculations will take us farther toward this goal, although essential uncertainties remain.

The lifecycle of PVC accounts for many but not all sources of dioxin. Controlled and uncontrolled waste combustion, landfill fires, and accidental building and vehicle fires are sources of dioxin that involve PVC. Assume, therefore, that half of dioxin emissions are attributable to PVC, and could be prevented by phasing out the use of PVC (although for some time after a phase-out, emissions would continue from combustion of PVC produced in the past). Then, under high-case assumptions, the elimination of PVC prevents half of 22,300, or 11,150 cancers annually. The policy of doing nothing fails to prevent those 11,150 cancers.

The latest and most comprehensive study of the cost of elimination of PVC, performed for Environment Canada in 1997, was based on prices and market conditions in Canada in 1993.[11] In research currently in progress, my co-workers and I have calculated that the Environment Canada study implies an average cost increase of US $0.55 per pound (in 2002 dollars) for replacement of PVC by alternative products. Consumption of PVC in the U.S. and Canada amounted to 13.4 billion pounds in 2001.[12] If consumption is proportional to population, then U.S. consumption is 90% of that amount, or 12.1 billion pounds. The cost of replacing all PVC consumption in the U.S can thus be estimated at roughly 12.1 billion pounds * $0.55/pound = $6.7 billion.

Returning to the underlying question of policy evaluation, the maxmin principle calls for an evaluation of which worst case is least harmful. With the several illustrative assumptions used here, one worst case fails to prevent 11,150 cancers, while the other imposes needless costs of $6.7 billion. These impacts are logically incommensurable: there is no natural, meaningful way to assign dollar values to profound health impacts such as cancer. Application of cost-benefit analysis to health and environmental regulation is frequently stymied by exactly this obstacle.[13] However, in the more modest spirit of cost-effectiveness analysis, it is easy to calculate that the hypothesized prevention of 11,150 cancers for $6.7 billion amounts to $600,000 per prevented cancer. This is much lower than the costs of many environmental regulations that regulatory critics have complained about in recent years.[14] Moreover, elimination of PVC would have other health benefits – including prevention of cancers caused by other hazardous by-products of the PVC lifecycle – beyond the dioxin-related benefits. Thus, under the assumptions used here, it would prevent cancers at a lower cost per case than $600,000.

Conclusions

This paper both illustrates the application of the economic theory of precaution, and suggests an argument about policies toward dioxin that bears further investigation. Economic theorists have demonstrated that, in cases of pure uncertainty, knowledge of the most extreme possible outcomes, the outer bounds of the possible, is all that is needed for optimal policy decisions. If, in addition, society is risk-averse toward the potential outcomes, then the maxmin principle should be adopted: choose the policy with the least harmful worst case.

The practical implication of these theories is demonstrated by high and low case calculations for dioxin. To allow specificity in the discussion, the calculations relied not only on established evidence, but also on several illustrative assumptions. However, if these assumptions are even approximately correct, they suggest that an ambitious policy measure, the elimination of PVC, may be well justified in precautionary terms.

References

[1] Arrow K. and Hurwicz L.; (1972) in Uncertainty and Expectations in Economics (Carter, C.F. and Ford, J.L., Eds.), Basil Blackwell, ISBN 06-7806-277-3
[2] Woodward, R.T. and Bishop, R.C.; (1997) Land Economics 73, 492
[3] Kelsey, D.; (1993) International Economic Review 34, 297
[4] Gilboa, I. and Schmeidler, D.; (1989) Journal of Mathematical Economics 18, 141
[5] Becher, H., Steindorf, K., and Flesch-Janys, D.; (1998) Environmental Health Perspectives 106, 663
[6] Steenland, K., Deddens, J., and Piacitelli, L.; (2001) American Journal of Epidemiology 154, 451
[7] Portier, C.; (2000) Food Additives and Contaminants 17, 335
[8] U.S. Environmental Protection Agency (2001) EPA-SAB-EC-01-006
[9] U.S. Environmental Protection Agency (2000) EPA/600/P-00/001Bb
[10] Thornton, J.; (2000) Pandora's Poison, MIT Press, ISBN 0-262-20124-0
[11] CHEMinfo Services Inc.; (1997) A Technical and Socio-Economic Comparison of Options to Products Derived from the Chlor-Alkali Industry, Environment Canada
[12] American Plastics Council (2002), The Resin Review
[13] Ackerman, F., and Heinzerling, L.; (2002) University of Pennsylvania Law Review 150, 1553
[14] Heinzerling, L., and Ackerman, F.; (2002) Cornell Law Review 87, 648