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Risk Assessment and Environmental Benefits Analysis

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ABSTRACT

Benefits analysis applied to regulations involving health risks, such as primary air quality standards, faces two types of uncertainty. One is regulatory uncertainty: absence of information concerning the supply of and demand for regulated air quality. The second is scientific uncertainty: lack of information on thresholds defining air quality health standards. When these uncertainties interact, they define "net social risk," modeled as a social welfare constraint on maximization of regulatory benefits. This risk can be lowered by raising standards or by reducing regulatory and scientific uncertainty. Current policy does neither, limiting options for regulatory efficiency and raising net social risks.

INTRODUCTION

Benefits analysis is increasingly used to weigh environmental policy alternatives and gain control over the regulatory process.[1] An important aspect of this process is improvement of public safety including reductions in health risks. One recent instance is President Reagan's Executive Order calling for "regulatory impact analysis," using "net social benefits" as a major criterion.[2] Like other recent administrative actions, the order calls on policy makers to analyze not only costs and benefits, but also the riskiness of regulatory alternatives.[3] Here and elsewhere in the law, the relationship betwen benefits analysis and risk assessment is ambiguous.

In some cases, risks are treated as separate from net benefits. For example, the Clean Air Act as amended in 1977 precludes benefits analysis

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1. Baram, *Cost-Benefit Analysis: An Inadequate Basis for Health, Safety and Environmental Regulatory Decisionmaking*, 8 ECOLOGY L. Q. 473 (1980); Field, *Patterns in the Laws on Health Risks*, 1 J. POL'Y ANALYSIS & MGMT. 257 (1982).

2. Exec. Order No. 12,291, 46 Fed. Reg. 13,193 (1981).

3. EPA, Draft of Guidelines for Performing Regulatory Impact Analysis, App. A: Regulating Impact Analysis Guidance for Benefits (April 5, 1982).

for the purpose of setting primary standards for criteria pollutants.[4] Instead, these standards must be set to avoid risks to human health.[5] In other cases risks and benefits are treated as comparable. More than 10 federal statutes require or propose the use of "risk-benefit analysis" as if an accepted basis for analysis existed. Unfortunately, it does not.[6]

This article analyzes the relationship between benefits analysis and environmental risk assessment, focusing on problems of primary standards for air quality. It first compares uncertainty in regulatory benefits analysis with uncertainty in assessing health risks. It then argues that setting air quality standards involves both types of uncertainty. Their interaction leads to the development of a combined measure: "net social risk." Net social risk is then modeled as a constraint on net social benefits of regulation. Whether it is a binding constraint reflects ethical judgments about social welfare involving trade-offs between benefits and risk. The article concludes with some implications of these trade-offs for environmental policy.

REGULATORY AND SCIENTIFIC UNCERTAINTY

Regulatory Uncertainty

Benefits analysis for a good such as air quality involves estimation of willingness to pay in terms of the area under a demand curve derived from direct or indirect expressions of individual preferences. Assuming such a demand curve can be estimated, alternative supply levels of clean air can then be described as a function of different regulatory states-of-the world. An increase in the Environmental Protection Agency's (EPA) primary SO_2 standard, for example, can be expected to lead to a shift in the supply of air quality measured for this criteria pollutant. In principle, estimates of increases in consumer surplus are then calculable.[7]

At least two types of uncertainty arise in this calculation. First, on the demand side, exact estimates of willingness to pay are difficult. Demand

4. Clean Air Act § 108, 42 U.S.C. § 7408 (Supp. I 1977).

5. Clean Air Act § 109, 42 U.S.C. § 7409 (Supp. I 1977). In 1979, EPA, commenting on the revised standard for ozone, stated that the primary standard should be set "to protect public health adequately. Considerations of cost of achieving these standards or of the existence of technology to bring about needed reductions of emissions are not germane to such a determination. . . ." 44 Fed. Reg. 8,211 (1979).

6. Moreau, *Quantitative Assessments of Health Risks by Selected Federal Agencies: A Review of Present Practices with Special Attention to Non-Carcinogenic Substances* 3–9 (1980) (Environmental Protection Agency Report); Moreau, Hyman, Stiftel & Nichols, Elicitation of Environmental Values in Multiple Objective Water Resource Decision Making 37 (1980) (Dept. of City & Regional Planning, U.N.C.); Ricci & Molton, *Risks and Benefits in Environmental Law*, 214 SCI. 1096 (1981).

7. *See* R. JUST, D. L. HUETH & A. SCHMITZ, APPLIED WELFARE ECONOMICS AND PUBLIC POLICY 69–83; *see also* A. M. FREEMAN, III, THE BENEFITS OF ENVIRONMENTAL IMPROVEMENT 1–59 (1979).

estimates are subject to bias especially in cases of public goods such as air quality, although recent research suggests the degree of bias is sensitive to the estimation method.[8] These errors can in principle be overcome with increasingly sophisticated methods.[9] A second source of uncertainty is on the supply side. Increases in the supply of clean air are inherently difficult to measure. The ability of federal regulation to achieve targeted state and regional air quality levels is also uncertain. This is due to lack of knowledge concerning the way a change in standards affects the complicated transmission mechanism linking emissions from point sources to air quality. Furthermore, simply choosing a particular primary air quality standard does not mean that the standard will be implemented and enforced through state implementation programs (SIP's) and secondary standards.[10]

Together, these problems can be described as *regulatory uncertainty*, reflecting the difficulty of estimating benefits resulting from air quality standards when regulated levels are not achieved with certainty. Even where they are, preferences for the result may be inaccurately represented by estimates of demand. Regulatory uncertainty is related to health risk, but is distinct from the type of uncertainty most important in current risk assessment studies.

Scientific Uncertainty

Under the Clean Air Act as amended in 1977, the Federal Government is responsible for primary air quality standards stringent enough to protect the public health with an "adequate margin of safety."[11] Assessment of environmental risk inside the EPA has focused on the health effects of Primary National Ambient Air Quality Standards (PNAAQS). When a particular pollutant "may reasonably be anticipated to endanger the public health or welfare," the EPA Administrator must publish an air quality criteria document which forms the scientific basis for the standard.[12]

PNAAQS defines the degree of protection from adverse health effects to be achieved, stated in terms of time-averaged pollutant concentrations and the expected number of cases in which these concentrations will be

8. Bishop & Heberlein, *Measuring Values of Extramarket Goods: Are Indirect Measures Biased?*, 61 AM. J. AGRIC. ECON. 926 (1979); Brookshire, Thayer, Schulze & d'Arge, *Valuing Public Goods: A Comparison of Survey and Hedonic Approaches*, 72 AM. ECON. REV. No. 1 at 165 (1982); Desvousges, Smith & Fisher, Direct and Indirect Methods of Valuing Public Goods: Further Evidence (1982) (Dept. of Econ., U.N.C.).

9. Fisher & Smith, *Economic Evaluation of Energy's Environmental Costs with Special Reference to Air Pollution*, 7 ANN. REV. ENERGY 1 (1982).

10. McKean, *Enforcement Costs in Environmental and Safety Regulation*, 6 POL'Y ANALYSIS 269 (1980).

11. Clean Air Act § 109, 42 U.S.C. § 7409(b)(1) (Supp. I 1977).

12. Clean Air Act § 108, 42 U.S.C. § 7408(a)(1)(A) (Supp. I 1977).

exceeded per unit of time. Health risks associated with a standard are risks of adverse health effects for a given population in a given time period when the standard is being met. These risk assessments are essentially estimates grounded in scientific data. The uncertainty associated with these estimates is meant to be distinct from the regulatory uncertainty raised by the possibility of non-compliance or non-enforcement.[13]

Primary standards accompanying the criteria document also are theoretically distinct from attainment costs. Neither cost estimates nor the uncertainty surrounding them are a germane consideration, entering only at the level of state implementation and the development of secondary standards to protect the public welfare.[14] This separation of costs from health risks has motivated a careful inquiry into the definition of such risks, but has heightened the sense that some basis for comparing net benefits with health risks must be found, especially in a practical regulatory environment in which primary standards must be defended in terms of their secondary effects on the population at risk.

Scientific analysis of health risks associated with PNAAQS is based on two presumptions. The first is that it is possible to identify some level of air quality which functions as a type of scientific threshold so that a "margin of safety" can be determined. Below this threshold there are unacceptable risks of health impairment to the population. Second, it is presumed possible to model the relationship between human health and air quality, so that this scientific threshold can be determined and primary standards set to avoid it. Both presumptions are questionable given existing knowledge. The level of air quality identified as a threshold is uncertain because of an absence of complete information concerning pollutants and their health effects. Even where scientific information on health effects exists, it is subject to false associations between pollutants and morbidity and mortality.[15]

This scientific uncertainty is the main focus of environmental risk assessment. Where hard scientific information cannot be found, recent EPA research has extended its efforts to reduce risk by encoding more subjective, "transcientific" judgments to estimate the probability of air quality impacts on human health. These estimates are nonetheless a result of scientific judgments by experts on chemical and biological processes.[16]

13. Feagans & Biller, *Assessing the Health Risks Associated with Air Quality Standards*, 3 ENVTL. PROF. 235 (1981).

14. O'Connor, *Overview of the Criteria Review and Standard Setting Process*, EPA OFFICE OF AIR QUALITY PLANNING & STANDARDS REP. (1981).

15. *See* R. CRANDALL & L. LAVE, THE SCIENTIFIC BASIS OF HEALTH AND SAFETY REGULATION (1981).

16. Feagans & Biller, *supra* note 13; Feagans & Biller, *A General Method for Assessing Health Risks Associated with Primary National Quality Standards* (1981) (Environmental Protection Agency Report; Bazelon, *Risk and Responsibility*, 65 A.B.A. J. 1068 (1979); Richmond, *A Framework for*

In summary, *regulatory uncertainty* involves absence of information concerning the supply of and demand for regulated air quality. This is due to ignorance about the transmission mechanism from point source abatement to air quality, errors in implementing and enforcing primary standards, and errors in estimating consumer preferences. Reducing this uncertainty would improve policy makers' ability to estimate the impacts and thus the net benefits of regulation. *Scientific uncertainty* results both from a lack of information on the relationship between human health and air quality, and from resulting errors in determining threshold levels where unacceptable risks are posed to certain populations. Reducing scientific uncertainty would improve policy makers' ability to set primary standards in such a way that health thresholds for these groups are not crossed.

NET SOCIAL RISK

In the formulation of environmental policy, regulatory uncertainty and scientific uncertainty are not separable. Their interaction is one cause of current regulatory dilemmas. Regulatory uncertainty may be defined with respect to the choice of a primary standard and an accompanying set of secondary standards and state implementation plans. Restricting attention to a single criteria pollutant such as SO_2, the standard in period i is simply A_i. In these terms, the regulatory dilemma is as follows. If the impact measured for SO_2 resulting from PNAAQS on sulfur oxides is uncertain, there is some probability that realized air quality after implementation and enforcement will fall below the threshold level deemed an unacceptable risk to human health. However, since this threshold is itself uncertain, even a PNAAQS with known impacts on air quality may have uncertain effects on health risks to well-defined populations. Therefore, the interaction of the two types of uncertainty becomes the relevant concern.

The interaction of regulatory and scientific uncertainty produces a composite measure of the impact of a particular standard on human health, which may be defined as *net social risk*. To see this more clearly, let

$Q(A_i)$ = a random variable defining the level of air quality associated with a particular standard, in this case for SO_2.

T_i = a random variable defining the threshold level of air quality deemed an unacceptable risk to the health of a well-defined population.

Assessing Health Risks Associated with National Ambient Air Quality Standards, 3 ENVTL. PROF. 224, 229 (1981); Richmond, McCurdy & Jordan, Risk Analysis in the Context of National Ambient Air Quality Standards (1982) (paper presented at the annual meeting of the Air Pollution Control Association, New Orleans).

These variables are assumed to be continuously distributed with non-zero mean and variance.

$$E(Q) = \mu_Q; V(Q) = \sigma_Q^2$$
$$E(T) = \mu_T; V(T) = \sigma_T^2$$

Note that σ_Q^2 and σ_T^2 represent regulatory and scientific uncertainty respectively.

In more formal terms, the regulatory dilemma described above is that for any well-defined group, the level of air quality Q associated with a standard A_i may be less than the threshold level deemed an unacceptable health risk T_i. The probability of this event is the net social risk associated with the standard. Net social risk R exists where there is some positive probability that the level of air quality associated with the implementation and enforcement of the PNAAQS is less than that prescribed by the threshold.[17] The positive probability of this event is given as

$$R = \Pr(Q < T) > 0$$
$$= \Pr[(Q - T) < 0] > 0.$$

The difference (Q − T) defines a third random variable $\Delta(A_i)$, the convolution of Q and (−T), distributed with its own mean and variance. This variable captures the difference between the air quality achieved under the standard and the scientific threshold of acceptable risk. Specifically, it is the case that

$$E(\Delta) = \mu_\Delta = \mu_Q - \mu_T$$
$$V(\Delta) = \sigma_\Delta^2 = \sigma_Q^2 + \sigma_T^2 - 2\sigma_{QT}.$$

The expectation μ_Δ is, therefore, a function of the expected impact of the standard on air quality (μ_Q) as well as the expected threshold of health risk (μ_T). Since uncertainty surrounds both of these air quality levels, the variance of Δ is a measure of uncertainty from both regulatory and scientific sources, since σ_Δ^2 is an additive function of σ_Q^2, σ_T^2, and σ_{QT}. Because regulatory standards must be set once a threshold is determined, lags associated with this process imply that the contemporaneous correlation between Q and T, σ_{QT}, is zero.[18]

This formulation allows a more precise description of the interaction of regulatory and scientific uncertainty resulting in net social risk. If R is judged to be unacceptably high, there are two major ways to reduce

17. This requires that the densities for Q and T overlap for some interval, which seems plausible if standards are set so as to just meet the threshold level of health risk, as currently mandated.

18. If standards were set without a lag, then σ_{QT} could arguably be large and positive. This would offset σ_Q^2 and σ_T^2 in the expression for σ_Δ^2 to a degree determined by the relative magnitude of these terms. A plausible interpretation is that if regulations could respond contemporaneously to health risks, such quick responses could mitigate scientific and regulatory uncertainty.

it. First, policy makers can attempt to raise the expected effect of the standard on air quality. Given a fixed level of uncertainty around μ_Q due to problems of translating the standard into actual air quality, one obvious way to raise μ_Q is by raising the primary standard. This assumes that the expected threshold defining an acceptable health hazard to the population (μ_T) is fixed on the basis of scientific data. If this threshold is considered more subjectively, different interpretations may lead to different thresholds. If we assume that μ_T is fixed, however, then setting μ_Q low raises the net social risk that a threshold of unacceptable health risk will be crossed. Setting it higher lowers net social risk, but is likely to involve greater regulatory costs. This trade-off will become more explicit in a constrained-maximization framework below.

Turning to the variance term σ_Δ^2, it is clearly possible to reduce the uncertainty that the standard is too low by reductions in either σ_Q^2 or σ_T^2 or both. Regulatory uncertainty can presumably be reduced by increased information on the linkages between primary standards and air quality. In addition to better measurement, information on the transmissions of SO_2 from point sources to general air quality will reduce σ_Q^2, together with assurance that the standard will be implemented and enforced. Scientific uncertainty, the focus of EPA's risk assessment efforts, can be reduced by better information on links from SO_2 to morbidity and mortality. This will allow more well-defined thresholds for particular criteria pollutants.[19]

In summary, net social risk may be considered the probability that standards are too low to avoid a threshold of hazard. The fewer cases are accepted of adverse health affects per unit of time and the lower primary standards are set in relation to this threshold, the greater this probability will be. The more uncertainty which surrounds both standard and threshold, the more uncertainty exists over whether the standard is sufficient to avoid such hazards.

NET SOCIAL RISK AS A CONSTRAINT ON REGULATORY BENEFITS

Choosing an acceptable level of net social risk is fundamentally an ethical question, because standards and thresholds involve normative judgments. "Acceptable" health hazards defining a threshold may result in damage or even death if the standard chosen is low. Willingness to accept these hazards must result from an explicit or implicit trade-off between net social benefits and human life and health. The assessment

19. Feagans & Biller, *supra* note 13.

of risk is thus linked to the value attached to morbidity and mortality.[20] If net benefits are measured as efficiency gains, the normative character of net social risk suggests that this risk is part of a social welfare function constraining efficient economic choices.

Treating net social risk in this way acknowledges its relationship to other issues of social welfare including equity. Indeed, the distinction between equity and acceptable net social risk is blurred. To decide how high the probability should be that a standard is within range of an unacceptable threshold is to put a value on adverse effects to some individuals. A decision to accept high rather than low net social risks is therefore a decision to treat different persons differently. Such distinctions are at the heart of equity judgments, making them a question of social welfare.[21]

One response minimizing the importance of such questions is that if net social risks are borne collectively, they impose comparatively little private burden as the numbers in the population at risk increase.[22] But as Anthony Fisher noted, the nonexcludable public good characteristics of risk regulations may lead to the opposite conclusion: risks may rise with increasing numbers if each person bears the same amount.[23] Furthermore, if the population at risk varies over time, the assumption of collective risk-bearing does not hold either. For a variety of reasons, individuals will not be identically susceptible to health effects from air pollution or other sources over time, making collective risk-bearing implausible.

In addition to equity, net social risk is conceptually linked to what Talbot Page terms the fallacy of regulatory "false negatives."[24] Most risks subject to government regulation proceed on the assumption that pollutants must be proven hazardous to be considered risky. If evidence of hazard is scanty, regulatory decisions setting high standards are viewed as costly and wasteful. Such overregulation is considered analogous to a "false positive" or Type I statistical error, in which the null hypothesis of no effect is true and is erroneously rejected by overzealous regulation. This view is advanced in a variety of recent EPA documents and policy pronouncements.[25]

In contrast, "false negatives" occur when failure to find evidence of adverse health effects leads to the fallacious conclusion that no such effects

20. Richmond, McCurdy & Jordan, *supra* note 16; Rowe, *Government Regulation of Societal Risks*, 45 GEO. WASH. L. REV. 944, 967 (1977).

21. *See* D. MACRAE, JR., THE SOCIAL FUNCTION OF SOCIAL SCIENCE (1976).

22. Arrow & Lind, *Uncertainty and the Evaluation of Public Investment Decisions*, 60 AMER. ECON. REV. 364 (1970).

23. Fisher, *Environmental Externalities and the Arrow-Lind Public Investment Theorem*, 63 AMER. ECON. REV. 722 (1973).

24. Page, *A Generic View of Toxic Chemicals and Similar Risks*, 7 ECOLOGY L.Q. 207 (1978).

25. EPA, *supra* note 3, at 7; EPA's High Risk Carcinogen Policy, 218 SCI. 975 (1982).

can occur. Acceptance of the null hypothesis of no effect may prove false when more is known about the structure of the problem. In the case of air quality, minimizing the probability of false negatives requires reduced uncertainty regarding both regulatory impacts and scientific links from pollution to human health. As Page notes, "The less uncertain the structure (i.e., the more information available), the more likely it is that a negative finding will lead to a valid conclusion."[26] Reducing both regulatory and scientific uncertainty, and therefore net social risk, makes this structure more clear.[27]

Modeled as a social welfare constraint on economically efficient outcomes, net social risk can be related directly to benefits analysis. Let an objective function for net social benefits of regulation be defined in terms of expected air quality levels associated with a particular set of national ambient standards. An objective function (G) expresses the expected sum of measurable economic costs $C(A_i)$ and benefits $B(A_i)$ from air quality regulation over a time horizon of n periods. These are maximized when the expected sum of net benefits associated with standards $(A_0, A_1, \ldots A_i \ldots A_n)$ in periods 0 to n is greatest. Benefits are thus expressed as a function of air quality standards in each period.

Air quality standards are the choice variable leading to expected levels of air quality. When net social benefits are discounted at some rate r_i in each period, the expression for the expected sum of net benefits from regulation is as follows:

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26. Page, *supra* note 24, at 232.

27. Let the null hypothesis be such that the air quality associated with a PNAAQS is sufficiently high that the threshold of hazard is not crossed and no adverse health effects result so that $\Delta = (Q - T) \geq 0$. The alternative hypothesis is that it is crossed, leading to unacceptable hazards, so that $\Delta = (Q - T) < 0$. Hence:

$$H_o : (Q - T) \geq 0$$
$$H_a : (Q - T) < 0$$

The relationship between acceptance, rejection and the truth value of these hypotheses is shown in the table following, together with designation of false positive (Type I) and false negative (Type II) error.

Decision

State of the World	**Accept H_o**	**Reject H_o**
H_o true: $(Q - T) \geq 0$	correct decision	incorrect decision (false positive—Type I error)
H_a true: $(Q - T) < 0$	incorrect decision (false negative—Type II error)	correct decision

Since net social risk is given as $R = Pr[(Q - T) < 0] > 0$, a positive value of R can only result if there is some probability that the alternative hypothesis H_a: $(Q - T) < 0$ is true. A false negative finding is possible only if H_a is possible, in which case $R > 0$.

$$E[G(A_i)] = E\left[\sum_{i=0}^{n} \frac{B(A_i) - C(A_i)}{\pi_i(1 + r_i)}\right]$$

These net benefits are subject to regulatory uncertainty associated with the impact of the standards as described above.

Now let a social welfare function denote an acceptable level of net social risk R^* in each period, such that the actual level $R(A_i)$ is less than or equal to R^*. The social welfare function implies the constraint $R(A_i) \leq R^*$ on the maximization of net benefits. The problem is to maximize the expected level of discounted net benefits subject to the constraint posed by acceptable net social risk.

$$\text{Max } E[G(A_i)] = E\left[\sum_{i=0}^{n} \frac{B(A_i) - C(A_i)}{\pi_i(1 + r_i)}\right]$$

s.t.

$$R^* - R(A_i) \geq 0$$
$$A_i \geq 0$$

The Lagrangean expression follows, where λ is the shadow value or Lagrangean multiplier associated with the constraint.

$$L = E\left[\sum_{i=0}^{n} \frac{B(A_i) - C(A_i)}{\pi_i(1 + r_i)}\right] + \lambda\,[R^* - R(A_i)]$$

Kuhn-Tucker Conditions for a maximum are

$$(1)\quad \frac{\partial L}{\partial A_i} \leq 0 \qquad A_i \frac{\partial L}{\partial A_i} = 0$$

$$(2)\quad \frac{\partial L}{\partial \lambda} \geq 0 \qquad \frac{\lambda \partial L}{\partial \lambda} = 0$$

$$A_i \geq 0 \quad \lambda \geq 0$$

These conditions can be useful in measuring the trade-offs between net economic efficiency benefits and net social risks. The first pair are conditions for a maximum level of net benefits from regulated air quality. Where $\frac{\partial L}{\partial A_i} = 0$, if it is the case that $A_i > 0$, an interior maximum is achieved by setting expected discounted marginal benefits of regulation (MB) equal to expected discounted marginal costs (MC). However, if the shadow value of net social risk is positive (the risk constraint is binding), first order conditions for a maximum require that

$$\frac{\partial L}{\partial A_i} = MB - MC - \frac{\lambda \partial R}{\partial A_i} = 0$$

so that

$$MB - \frac{\lambda \partial R}{\partial A_i} = MC.$$

In other words, optimality requires that expected discounted marginal benefits of regulation, minus λ times the marginal value of risk, be set equal to marginal costs. A "risk factor" equal to $\frac{\lambda \partial R}{\partial A_i}$ has entered the efficiency conditions for a maximum. However, if $\lambda = 0$ the risk constraint is not binding, so first order conditons for a maximum are

$$\frac{\partial L}{\partial A_i} = MB - MC = 0$$

so that

$$MB = MC.$$

Here the risk factor does not affect the marginal efficiency conditions. Hence, whether economic efficiency is constrained by a risk factor depends entirely on whether R^* is set so that the risk constraint is binding. A similar story may be told if $A_i = 0$ and a corner solution represents a maximum.

The second set of conditions concerns the risk constraint itself. If the risk constraint is binding and the shadow value is positive, then $R^* = R(A_i)$. As the shadow value rises, so does the expression $\frac{\lambda \partial R_i}{\partial A_i}$, so that the risk factor in the marginal conditions increases in magnitude. The value of λ is tantamount to the social value of acceptable risk. If the constraint is binding, estimating this value is a necessary condition for the formulation of policy.

Note, however, that given R^* (a social welfare judgment) and a particular value of λ associated with a binding risk constraint $R^* = R(A_i)$, it is possible to make the constraint non-binding by reducing $R(A_i)$ below

R*. As discussed above, this can result either from raising the expected impact of the standard on air quality (raising μ_Q) or from reduction in regulatory and scientific uncertainty (lowering σ_Q^2 or σ_T^2). Increases in the expected impact of the standard will be likely to raise the costs of regulation so that risks are traded off directly for regulatory costs. Reductions in both regulatory and scientific uncertainty, however, may involve a more favorable trade-off. Since knowledge of the structure of regulation and health hazards has general social utility, it may cost less to trade risk for information than for regulation. Increasing regulatory and scientific certainty, in short, can loosen the risk constraint at the same time that it improves the general store of knowledge, allowing unconstrained pursuit of net social benefits.

POLICY IMPLICATIONS

To summarize, the above analysis is predicated on a distinction between regulatory and scientific uncertainty. Regulatory uncertainty confronts the ability of benefits analysis to estimate demand for regulations affecting air quality and the impact of these regulations on the quantity of clean air supplied. Health risks, in contrast, are subject to scientific uncertainty about the relationship between pollutants and acceptable thresholds of human morbidity and mortality. Regulatory decisions respecting national ambient air quality standards involve both types of uncertainty. Taken together, these uncertainties define the net social risk that standards may be too low to maintain the thresholds called for under law. Once social welfare judgments establish an acceptable level of net social risk, this risk can be considered a constraint on the net benefits of regulation, which can only be loosened by increasingly stringent standards or reductions in regulatory or scientific uncertainty.

These results have a number of implications for environmental policy. First, they suggest the inescapable interplay between regulation and human health associated with environmental hazards. Because this interplay has social welfare implications, such regulations can never be reduced to pure questions of economic efficiency as long as the constraint of net social risk is binding. Hence, there is a need to identify and estimate explicitly the shadow value of acceptable net social risk. Policy makers can then make social welfare judgments which, while still normative, are at least non-arbitrary. Estimating the shadow value of net social risk is therefore an important task of policy research.[28]

28. Gallaher & Smith, Measuring Values for Environmental Resources Under Uncertainty (1982) (Dept. of Econ., U.N.C.).

A second implication is the attractiveness of policies which promote greater regulatory and scientific certainty. Regulatory certainty can be increased through research in the entire range of questions linking benefits to the supply of and demand for environmental regulation.[29] Scientific certainty can be increased through efforts inside EPA and elsewhere to monitor and estimate the hazards posed by environmental pollution.[30] These increases in information can make the net social risk constraint non-binding, freeing regulators to pursue efficiency goals. If such information is useful in other contexts, its acquisition is likely to be less costly than increasingly stringent standards. Where information is simply unavailable, especially in the short run, increasing standards may be a second-best response to unacceptable risk. But a first-best response, especially in the long run, may be increased certainty resulting from expanded research programs in policy and environmental science. Because the two types of uncertainty may be interrelated, research on regulation and scientific hazards must be closely tied in conduct and performance. As Crandall and Lave demonstrate, the scientific basis of regulation is an increasingly important field of interdisciplinary inquiry.[31]

A final set of points questions the wisdom of current policy. It is ironic that Administration advocates of regulatory efficiency, who champion the estimation of net regulatory benefits under Executive Order 12,291, have reduced support for research activities which might provide insight into the structure of regulation and its impact on health. Reductions in enforcement of environmental standards as well as declining numbers of scientific staff at EPA and elsewhere will be likely to increase both regulatory and scientific uncertainty in the future. If the foregoing analysis is correct, these increases will reduce the flexibility of policy makers to substitute information for regulation. This leaves a more difficult policy choice between costly increases in environmental standards—or admitted increases in net social risk—as both regulatory impacts and health effects become more uncertain. Current policy, opposed to increased stringency of standards, appears to tolerate increased risks and even to loosen the definition of acceptable health hazard thresholds.[32] A far more attractive

29. *E.g.*, Bailey, *Risks, Costs, and Benefits of Fluorocarbon Regulation*, 72 AMER. ECON. REV. No. 2 at 247 (1982); Jordan, Richmond & McCurdy, Regulatory Perspectives on the Use of Scientific Information in Air Quality Standard Setting (1981) (paper presented at the annual meeting of the American Association for the Advancement of Science); L. LAVE, STRATEGY OF SOCIAL REGULATION: DECISION FRAMEWORK FOR POLICY (1981); Regans, Dietz & Rycroft, Risk Assessment in the Policy-Making Process: Environmental Health and Safety Protection (1982) (paper presented at the annual meeting of the American Political Science Association).

30. *See* Feagans & Biller, *supra* note 16.

31. CRANDALL & LAVE, *supra* note 15.

32. *EPA's High Risk Carcinogen Policy*, *supra* note 25.

option would be to reduce both regulatory and scientific uncertainty, freeing government to pursue efficiency in regulation without increasing either standards or levels of net social risk. Increasing alarm over environmental health hazards resulting from failure to achieve regulatory standards suggests that current policies may not reflect the shadow value of net social risk held by society as a whole. Estimates of this value will require further investigation.