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When is a Life Too Costly to Save? The Evidence from U.S. Environmental Regulations[1]

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Under certain environmental statutes the EPA is required to balance costs and benefits in setting standards, whereas under others this is prohibited. This paper examines EPA regulatory decisions made under three statues, two of which require balancing and one of which does not. Using discrete choice models, we find that costs and benefits are significant explanatory variables for all three sets of decisions. This suggests that balancing occurred in each case; however, the value (implicit in these decisions) of avoiding a cancer case varies widely. We also find that a 1987 court ruling effectively curtailed whatever balancing occurred under the statute that prohibited it. © 1996 Academic Press, Inc.

1. INTRODUCTION

Under various environmental statutes the U.S. Environmental Protection Agency (EPA) is responsible for issuing regulations to protect the public from exposure to pollution. These regulations include outright bans of certain products (some pesticides, products containing asbestos) and, more commonly, limitations on the amount of pollution a factory or vehicle can emit.

Most economists would argue that these regulations should be made—at least in part—on the basis of benefit–cost analyses: an environmental standard should be set where the marginal cost of setting a slightly more stringent standard outweighs the marginal benefit of increased stringency. EPA, however, is sometimes restricted by Congress in what factors it can consider in issuing regulations. For example, under those provisions of the Clean Air Act pertaining to ambient standard-setting, costs cannot be taken into account, whereas for effluent standards under the Clean Water Act, costs are to be considered but benefits are not. Only two environmental statutes—the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Toxic Substances Control Act (TSCA)—actually

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require that the benefits and costs of regulation be balanced in setting environmental standards.

In this paper we investigate whether EPA has balanced costs and benefits in issuing regulations, regardless of whether it is allowed to do so by law. Our definition of "balancing" is as follows. If we examine a class of EPA regulations—for example, emissions standards for toxic air pollutants—do variations in costs and benefits across possible regulatory options help explain the standards selected? We shall conclude that EPA has taken both costs and benefits into consideration if (other things equal) a more costly standard is less likely to be selected, and a standard that saves more lives is more likely to be selected.

Intuitively, however, balancing requires more than this. It requires that the cost EPA is willing to incur to save an additional life be "reasonable." For each class of regulations that we examine, we calculate the implicit cost that EPA is willing to incur to save an additional life—the value of a statistical life implied by the regulations. The most important question is how this value compares with society's apparent willingness to pay to save the lives of people exposed to pollution: Is the value of a statistical life implicit in environmental regulations acceptable? It is also important to ask how this value varies across EPA program offices and across population groups. Is the value of a life saved higher for pesticide regulations than for air toxics? Does the agency implicitly attach more weight to saving the life of a worker exposed to pesticides or asbestos on the job than to the life of a consumer exposed to these pollutants?

A related issue that we examine is how EPA balances high risks to a relatively small number of individuals against smaller risks to larger populations. The definition of life-saving benefits used in most benefit−cost analyses—the expected number of lives saved in a population—implies that population risk is the regulatory outcome of interest. Much of environmental regulation is, however, based on the notion of reducing *individual* risk to an acceptable level. The notion of risk equity addresses not only the expected outcome of risks to specific populations (number of deaths), but also considers how the risks are distributed among individuals in the population. In practice, this has shifted some of the focus of regulation to the person who is most highly exposed to a pollutant (the so-called "maximally exposed individual" or MEI) and has required that the risks to the MEI be "acceptable" [1]. One of the issues we examine is how much weight EPA has given to individual risk versus population risk in its regulations.

To address these topics we extend the analysis of pesticide regulations in Cropper *et al.* [2] to the case of asbestos regulations issued under the Toxic Substances Control Act (TSCA) and to national emissions standards for hazardous air pollutants (the NESHAPS), issued under Section 112 of the 1970 Clean Air Act. Specifically, we consider:

(i) all cancer-causing pesticides used on food crops that went through EPA's Special Review process between 1975 and 1989;
(ii) all uses of asbestos regulated under the Toxic Substances Control Act (TSCA);
(iii) all carcinogenic air pollutants for which EPA set National Emissions Standards (NESHAPS) between 1975 and 1990.

In each case, we gathered data for each source of the pollutant (each crop in the case of pesticides), giving us a total of 245 pesticide regulations, 39 sources of asbestos regulated under TSCA, and 40 sources of four hazardous air pollutants—benzene, inorganic arsenic, radionuclides, and vinyl chloride.[2]

Our study is limited to the regulation of carcinogens because quantitative risk data are available more often for carcinogens than for other substances. This implies that the benefits of the regulation (the number of lives saved) can be quantified. We have also purposely selected some regulations issued under the two balancing statutes—TSCA and FIFRA—as well as regulations issued under the Clean Air Act (the setting of emissions standards for hazardous air pollutants) to see whether the enabling legislation makes any difference in the way in which EPA balances benefits and costs.

For each class of pollutants we estimate a model to explain EPA's regulatory decisions. Section 2 of the paper presents a model to explain whether EPA banned or did not ban each of the 39 uses of asbestos considered for regulation under TSCA. In Section 3 a similar model is estimated to explain EPA's decision to ban or not ban a pesticide (e.g., alachlor) for use on a particular crop (e.g., corn). In the case of hazardous air pollutants, the model presented in Section 4 explains why EPA selected the regulatory option that it did out of all the options considered for regulating each source of the pollutant. Section 5 presents our conclusions.

2. ASBESTOS REGULATIONS UNDER TSCA

In 1985 EPA announced its intent to ban the use of asbestos in 39 products under the Toxic Substances Control Act. Because TSCA is a balancing statute, EPA's Notice of Intent to Regulate was followed by a detailed assessment of the risks of exposure to asbestos fibers, as well as the costs of the ban [3].[3]

There is well-documented epidemiological evidence (as well as support from animal studies) indicating that some forms of asbestos are human carcinogens. This evidence is particularly strong for lung cancer, gastrointestinal cancer, and mesothelioma, a cancer of the lung or abdominal lining. Estimating the number of cancer cases associated with a particular asbestos-containing product (e.g. brakes lined with asbestos) requires estimates of the potency of asbestos—the likelihood of developing cancer as a function of asbestos exposure—as well as an estimate of exposure—the number of fibers inhaled as a result of using the product. In the Regulatory Impact Analysis accompanying EPA's final rule, the agency presented, for each product, exposure estimates (in millions of fibers inhaled per year) for various groups of workers and for consumers, as well as the number of cancer cases associated with each source of asbestos. Table I presents EPA's estimates, on a product-by-product basis, of the number of cancer cases that would be avoided if each product were banned in 1992. EPA was able to estimate these, and the cost of the ban, for 31 of the 39 products considered for regulation. Estimates of cancer cases avoided are based on 13 years of exposure, since the agency assumed that asbestos would be phased out of these products after a 13-year period. Two points

[2] A complete list of all documents consulted is available from the authors.

[3] TSCA allows EPA to ban the use of a substance that causes any unreasonable risk to man or the environment. [§ 6(a), 15 U.S.C. § 2605 (a) (1988)]

TABLE I
Costs and Benefits of Banning Asbestos

Product description	Gross total cost (mil. 1989 $)	Cancer cases avoided	Cost per cancer case avoided (mil. 1989 $)
	Products banned		
Drum brake linings (A/M)	13.87	136.3872	0.10
Brake blocks	2.82	12.9784	0.22
Disc brake pads LMV (aftermarket)	5.69	23.2356	0.24
Pipeline wrap	0.55	1.1196	0.49
Specialty paper	0.02	0.0330	0.61
Drum brake linings (OEM)	7.18	7.6476	0.94
A/C sheet, corrugated	0.15	0.0923	1.63
Disc brake pads HV	0.32	0.1948	1.64
A/C sheet, flat	1.72	0.6752	2.55
Disc brake pads LMV (OEM)	3.49	0.9063	3.85
Roofing felt	4.04	0.9717	4.16
Friction materials	2.06	0.4719	4.37
Non-roofing coatings	2.27	0.3833	5.92
Millboard	5.16	0.7399	6.97
Beater-add gaskets	97.94	5.9344	16.50
Clutch facings	10.93	0.5444	20.08
Roof coatings	75.63	1.9134	39.53
Sheet gaskets	85.69	1.9973	42.90
A/C pipe	178.53	3.9999	44.63
A/C shingles	31.66	0.4111	77.01
Automatic transmission components	0.20	0.0004	500.00
Asbestos protective clothing			
Rollboard			
Commercial paper			
Corrugated paper			
V/A floor tile			
Flooring felt			
	Products not banned		
Asbestos packing	0.49	0.0114	42.98
Beater-add gaskets/2	50.45	1.0472	48.18
Asbestos-reinforced plastics	40.58	0.6570	61.77
High grade electrical paper	58.79	0.5107	115.12
Sheet gaskets/PTFE	31.69	0.2219	142.81
Asbestos thread, yarn, etc.	159.15	0.6222	255.79
Sealant tape	41.19	0.1115	369.42
Acetylene cylinders	0.08	0.00003	2666.67
Missile liner	1001.67	0.3161	3168.84
Asbestos diaphragms	2314.75	0.2140	10816.59
Battery separators			
Arc chutes			

about these estimates are worth noting. First, the agency made no distinction as to when the cancer cases would occur. Estimates by Mauskopf [4] suggest that 50% of the cancer cases listed in Table I would occur between 2025 and 2054, while 30% would occur after 2054, due to the long latency period associated with asbestos. Second, in estimating the number of cancer cases avoided by banning asbestos, EPA assumed that all substitutes for asbestos were riskless, an assumption of dubious validity.[4]

To calculate the costs of the ban, EPA estimated the lost consumer-plus-producer surplus that would result if alternatives to asbestos were used.[5] Column 2 of Table I presents estimates of these losses, discounted at 3%. The cost per life saved (column 2 divided by column 1) appears in column 3.

2.1. *The Value of a Cancer Case Avoided*

A plot of regulatory costs and cancer cases avoided for the 31 products for which complete data are available (see Fig. 1) suggests that EPA indeed considered benefits and costs in issuing the asbestos decision: Products in the northwest corner of Fig. 1, showing low costs and high numbers of lives saved, are almost always banned, while products in the southeast corner, with high costs and low numbers of lives saved, are, for the most part, not banned.

Since cancer cases avoided are the only benefits of the asbestos ban mentioned by EPA (i.e., ecological risks were not a factor in the decision to ban asbestos-containing products), it is tempting to infer from Fig. 1 a threshold value of a cancer case avoided below which all products were banned. The two solid lines in Fig. 1 correspond to values of a statistical life of $10 million and $100 million dollars, respectively. Clearly, neither line fits the data perfectly: The rules ‘‘ban all products with cost per life saved ratios below $10 million ($100 million) dollars’’ yield incorrect predictions for some products.

To compute the threshold value of a cancer case avoided implied by the asbestos regulations we estimate a probit model that predicts the probability that asbestos

[4] Because our goal is to capture the information available to the agency at the time of each decision, we use official agency estimates of risks and benefits, even when these do not accurately measure the risk reduction associated with the ban, or the social costs of the ban.

[5] To do this, EPA modeled the markets for each of the asbestos products, based on observed market outcomes and assumptions about the existence and future price trends of substitute products.

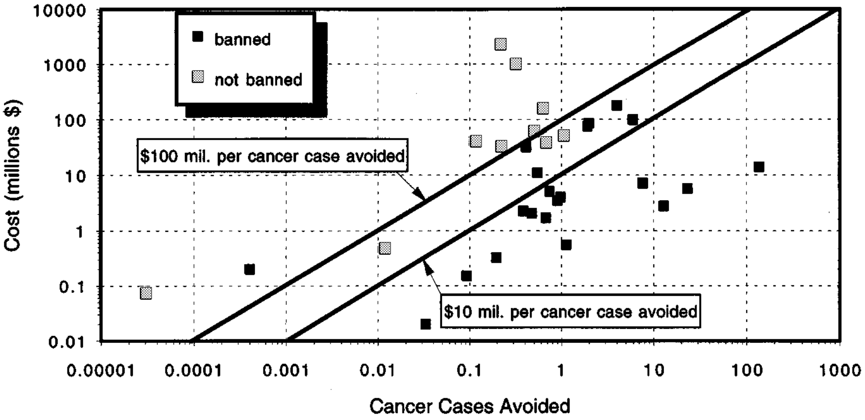

FIG. 1. Cost-effectiveness of the asbestos ban.

was banned for use in each product. Formally, we assume that the use of asbestos is banned in product i if the value of the cancer cases avoided (aM_i) minus the cost of the ban $(bC_i, b < 0)$ are positive,

$$aM_i + bC_i > 0. \tag{1}$$

This is equivalent to banning asbestos in product i if the cost per life saved, C_i/M_i, falls below $-a/b$, which is the threshold value of a cancer case avoided.

Since Eq. (1) does not fit the data perfectly, we estimate Eq. (2),

$$P(\text{Ban}_i) = P(aM_i + bC_i + u_i > 0), \tag{2}$$

where u_i is an error term that captures other factors, e.g., political considerations, that influenced the decision.

When Eq. (2) is estimated using the data in Table I, coefficients a and b are statistically significant (see column I of Table II), and the implied threshold value of a cancer case avoided is approximately $49 million (1989 dollars).

It is interesting to contrast this threshold with the average cost per cancer case avoided. In the *Regulatory Program of the United States*, the Office of Management and Budget [5] frequently lists various health and safety regulations in order of their average cost per life saved. The regulations with the highest cost per life saved are often environmental regulations. It is clear from Table I that, by focusing on automatic transmission components, with an average cost per cancer case avoided of $500 million, OMB could make EPA's asbestos regulations look bad. We believe that a more accurate description of the regulations is the threshold value computed in Table II.

A value of $49 million per life saved is, nonetheless, high—especially in contrast to estimates of the value of a statistical life based on willingness to pay for risk reductions. Estimates of the value of a statistical life based on compensating wage differentials [6, 7] suggest that workers in risky jobs require compensation on the order of $5 million per statistical life. While this compensation is for risks that are voluntarily borne, it is hard to imagine that the additional premium associated with involuntary risks is $44 million.

The threshold value of life implied by the asbestos regulations may, in fact, be higher than $49 million for three reasons. As noted above, EPA failed to acknowledge the timing of cancer cases avoided, even though it discounted the costs of the ban. If all cancer cases were avoided in 10 years rather than today, and if these cases were discounted at a rate of 3%, the threshold value estimated in Table II would rise to $65 million (1989 dollars). The threshold value is also biased downward because EPA ignored the risks of asbestos substitutes, and thus overstated the risk reduction that would follow a ban. Finally, many believe that EPA's risk assessment methodology results in ‘‘maximum plausible upper bound’’ estimates of risk. This implies that the *expected* number of cancer cases avoided is smaller than the numbers in Table I and, therefore, that the value of a cancer case avoided is larger.

Both of these factors were considered by the Fifth Circuit Court of Appeals in the *Corrosion Proof Fittings* case.[6] In this case, which overturned the asbestos ban,

[6] Corrosion Proof Fittings, 947 F.2d at 1218.

TABLE II
Factors Affecting the Probability that Asbestos is Banned

Variable name	(1)	(2)
Intercept	0.31	0.07
	(0.63)[a]	(0.12)
Gross total cost[b]	−0.099	−0.17
	(−2.03)	(−1.44)
Cancer cases avoided	4.85	
	(2.15)	
Occupational cancer cases avoided		11.76
		(1.43)
Nonoccupational cancer cases avoided		5.69
		(1.43)
Log likelihood	−6.42	−4.91
Percentage of decisions correctly predicted	87.0	87.0
Implicit value of a cancer case avoided[b]	48.61	
	[36.66, 60.55][c]	
Based on non-occupational exposure		34.39
		[6.96, 61.82]
Based on occupational exposure		71.01
		[12.83, 129.19]

[a] Numbers in parentheses are t statistics.
[b] Millions of 1989 dollars.
[c] Numbers in brackets are endpoints of a 95% confidence interval.

the court ruled that EPA had failed to take account of the timing of lives saved, and had ignored the health risks of asbestos substitutes. It was also determined that EPA had given insufficient weight to regulatory costs. In other words, the costs of the asbestos ban were too high relative to the benefits.

2.2. *Occupational vs Non-Occupational Exposure*

In Table I no distinction is made between cancer cases that result from occupational exposure to asbestos and those that do not. Because workers are, in general, exposed to higher levels of asbestos than consumers, EPA may weigh worker risks differently from consumer risks in deciding which products to ban. Equation (2) is easily modified to distinguish between occupational and non-occupational cancer cases avoided. Letting M_{1i} represent occupational cancer cases avoided and M_{2i} non-occupational cancer cases, (2) becomes

$$P(\text{Ban}_i) = P(a_1 M_{1i} + a_2 M_{2i} + bC_i + u_i > 0). \tag{3}$$

The ratios of the coefficients $-a_1/b$ and $-a_2/b$ measure, respectively, the value that EPA attaches to each type of cancer case. The corresponding geometric interpretation, if one plots C, M_1, and M_2 in three dimensions, is that EPA will ban all products whose cost falls below the plane $Z = -a_1/bM_{1i} - a_2/bM_{2i}$.

Unfortunately, reductions in occupational and non-occupational cancer cases are highly correlated. This is reflected in the second column of Table II, which shows the effect of separating cancer cases avoided into the two categories. While higher values of each benefit variable significantly increase the chances that a product is banned, neither variable is statistically significant at conventional levels. It is, nonetheless, interesting to note that the coefficient of occupational cancers avoided is about twice the coefficient of non-occupational cancers avoided. These coefficients imply, respectively, values per cancer case avoided of $71 million and $34 million.

EPA's tendency to value reductions in occupational exposures more highly than reductions in non-occupational exposures is confirmed below, in our analysis of pesticide regulations. The result is not surprising for two reasons. First, workers are, on average, exposed to much higher levels of asbestos than consumers. It is certainly reasonable that risk reductions be valued more highly, the higher the baseline risk.[7] Second, workers constitute an identified group, whose deaths from cancer are more easily linked to a specific source of exposure than are the deaths of consumers. For this reason, the political cost to the regulator of failing to regulate (making a mistake) is potentially higher for workers than for consumers.

On the other hand, to the extent that workers may already receive compensating wage differentials for exposure to asbestos, and, to the extent that their exposure is more voluntary than consumers', it is hard to justify the higher weight assigned to reducing occupational exposures.

3. PESTICIDE REGULATIONS UNDER FIFRA

Under FIFRA, EPA is allowed to cancel the registration of a pesticide if it causes "any unreasonable risk to man or the environment, taking into account the economic, social and environmental costs and benefits of the use of any pesticide."[8] If EPA suspects that a pesticide poses risks to human health or to ecosystems, the pesticide—or, more accurately, the active ingredients used in the pesticide—are subject to a Special Review.[9] This entails a formal risk–benefit analysis of the pesticide, after which EPA can either ban the pesticide for use on specific crops, restrict the manner in which the pesticide is applied, or allow its continued use, without modification.

Between 1975, when EPA initiated its first Special Review, and December of 1989, Special Reviews were completed for 37 active ingredients. Our analysis is restricted to the subset of these active ingredients that are suspected human carcinogens. Since, in principle, EPA can ban the use of an active ingredient on one crop but not on another, the number of possible regulations that can be issued for each active ingredient is equal to the number of crops on which the active ingredient is used. As shown in Table III, the 19 active ingredients examined were registered for use on a total of 245 food crops. We have restricted the analysis to food crops so that estimates of dietary cancer risk are available, as well as risk of cancer to mixers and applicators of pesticides.

[7] In the game of Russian Roulette, an individual is certainly willing to pay more to remove the first of five bullets from the chamber of a gun than he is willing to pay to remove the last bullet (see Jones-Lee [8]).

[8] FIFRA §2(bb), 7 U.S.C. §136(bb) (1988).

[9] In the 1972 amendments to FIFRA, EPA was given the task of reregistering the 50,000 pesticides in use in the United States at that time. In the 1978 amendments to FIFRA, this task was simplified by requiring reregistration of the 600 active ingredients used in the pesticides.

TABLE III
Active Ingredients in the Pesticide Database

Active ingredients	Year of decision	Number of food-use registrations	Number of proposed cancellations	Number of final cancellations
DBCP	1978	12	1	12
Amitraz	1979	2	1	1
Chlorobenzilate	1979	3	2	2
Endrin	1979	8	4	4
Pronamide	1979	4	0	0
Dimethoate	1980	25	0	0
Benomyl	1982	26	0	0
Diallate	1982	10	10	0
Oxyfluorfen	1982	3	0	0
Toxaphene	1982	11	7	7
Trifluralin	1982	25	0	0
EDB	1983	18	4	18
Ethalfluralin	1983	3	0	0
Lindane	1983	8	7	0
Silvex	1985	6	6	6
2,4,5-T	1985	2	2	2
Dicofol	1986	4	4	0
Alachlor	1987	10	3	0
Captan	1989	65	65	44
Totals		245	116	96

In considering whether or not to ban a pesticide, EPA examines risks of cancer to persons occupationally exposed to the pesticide—pesticide mixers and loaders and pesticide applicators—as well as to consumers of pesticide residues on food. Non-cancer health risks—risks of miscarriages or of possible fetal damage—are also examined. In addition, EPA considers adverse effects of pesticide exposure to fish, birds, and mammals. Against the risks of pesticide use, EPA is to balance the benefits of use—the reduction in consumer and producer surpluses that would result if the pesticide were banned.[10]

Table IV contains the means and standard deviations of the risks of pesticide use —the benefits of banning the pesticide—and the associated costs of the ban for 245 pesticide-crop combinations, separated according to whether or not the combination was eventually banned. Cancer cases avoided, per million exposed workers or consumers, represent EPA's estimate of the risk reduction associated with banning the pesticide.[11] These numbers must be multiplied by the size of the exposed population to calculate the number of cancer cases that would be avoided

[10] In practice, consumer surpluses are rarely computed. Instead, the benefits of pesticide use are measured as the cost of switching to substitute products, plus the value of resulting yield losses. These are usually quantified only for the first year after the proposed ban, and thus overstate the losses that would occur if better substitutes were developed for the banned pesticide.

[11] In practice this equals the number of cancer cases that are likely to develop as a result of a lifetime of exposure to the pesticide, since EPA assumes that alternatives to the pesticide in question are riskless.

TABLE IV
Means and Standard Deviations of Variables Used in Pesticide Model

Variable name	Uses that were banned			Uses that were not banned		
	No. of observations	Mean	Standard deviation	No. of observations	Mean	Standard deviation
Whether canceled	96	1.0	0.0	149	0.0	0.0
Dietary cancer cases avoided[a]	78	9.6×10^{-4}	3.5×10^{-3}	94	4.2×10^{-6}	1.4×10^{-5}
Applicator cancer cases avoided[a]	63	1.2×10^{-2}	2.1×10^{-2}	66	1.5×10^{-4}	7.3×10^{-4}
Mixer cancer cases avoided[a]	42	2.2×10^{-4}	8.8×10^{-4}	35	1.2×10^{-5}	9.9×10^{-6}
Annual cost of ban[b]	86	2.943	7.604	81	15.697	41.448
Whether yield loss	96	0.240	0.430	149	0.530	0.501
Reproductive effects	96	0.917	0.278	149	0.517	0.501
Danger to marine life	96	0.583	0.496	149	0.470	0.501

[a] Over the lifetimes of one million exposed persons.
[b] Millions of 1986 dollars; represents costs to producers only.

by banning the pesticide.[12] Since data on the size of the exposed population are not always reported, we treat the size of the exposed mixer/loader, applicator, and consumer populations as constant across crop/pesticide combinations. The mixer/loader population is assumed to be 1,000 workers, the applicator population 10,000 workers, while the relevant population for calculating dietary risks is the entire U.S. population.

Evidence of reproductive risks (risk of fetal deformity, lowered sperm count, or increased risk of miscarriage) are measured by a dummy variable, as are risks to marine life. EPA also distinguishes risks to birds and mammals; however, if an active ingredient harms mammals (birds), it always harms marine life. The same ‘‘subletting’’ problem occurs if an active ingredient is a mutagen or a teratogen; i.e., a substance that is a mutagen (teratogen) necessarily causes adverse reproductive effects.

The costs of banning the pesticide are measured as producer losses in the first year after cancellation, as reported by EPA. All costs are in 1986 dollars. When cost data are missing, a dummy variable is used to indicate whether yield losses are predicted to occur if the pesticide is banned.

3.1. *A Model of Pesticide Regulation*

It is tempting to plot the cost of pesticide bans against the number of cancer cases avoided, as was done for asbestos regulations (see Fig. 1); however, such a diagram would be misleading here. Because there are benefits to banning a

[12] To illustrate, if dietary cancer risk is 1 cancer case per million exposed persons, and the size of the exposed population is 250 million, we would expect to observe 250 cancer cases in the exposed population.

pesticide besides cancer cases avoided, the threshold inferred from such a diagram would overstate the value that EPA implicitly attaches to reducing cancer risks.

A better approach is to extend the probit model of Eq. (3) to include non-cancer benefits, and to use the resulting coefficients to infer the value attached to avoiding a cancer case for each of the three population groups. To estimate such a model we must confront the problem of missing data. As Table IV indicates, data on cancer risks to the three groups of interest are sometimes missing—either because estimates of exposure are not available, or because there are insufficient toxicological studies to quantify the potency of the chemical. In these cases we enter a zero for cancer cases avoided, but include a missing data dummy to distinguish these cases from instances where the actual risk estimate is zero. The coefficient of cancer cases avoided therefore measures the effect of this variable, assuming that data are available.

A probit model that predicts the probability of a pesticide ban appears in the first column of Table V. The model suggests that EPA has considered both the

TABLE V

Factors Affecting the Probability that a Pesticide is Banned

Variable name	(1)	(2)
Intercept	−1.493	−0.818
	(−3.016)[b]	(−1.396)
Dietary cancer cases avoided[a]	2.4×10^{-3}	−0.022
	(0.668)	(−0.939)
Diet risk missing	−0.733	−0.697
	(−2.153)	(−2.036)
Applicator cancer cases avoided[a]	5.6×10^{-4}	5.4×10^{-4}
	(2.406)	(2.268)
Applicator risk missing	−0.146	−0.222
	(−0.309)	(0.482)
Mixer cancer cases avoided[a]	0.003	−0.052
	(0.391)	(−1.957)
Mixer risk missing	0.251	−0.257
	(0.499)	(−0.452)
Annual cost of ban[c]	−0.043	−0.045
	(−2.189)	(−2.168)
Cost data missing × yield loss	−2.073	−2.153
	(−5.513)	(−5.455)
Cost data missing × no yield loss	−1.941	−1.870
	(−4.212)	(−4.049)
Reproductive effects	2.025	2.182
	(4.706)	(4.999)
Danger to marine life	0.251	−0.096
	(0.833)	(−0.299)
R_A diet		1.7×10^{-4}
R_A applicator		1.1×10^{-2}
R_A mixer/loader		3.1×10^{-5}
Log likelihood	−73.6	−69.7
Percentage of decisions correctly predicted	86.0	87.3

[a] Over the lifetimes of one million exposed persons.
[b] Numbers in parentheses are t statistics.
[c] Millions of 1986 dollars; represents costs to producers only.

costs and benefits of banning a pesticide in issuing regulations. The annual cost of the ban is significant and of the expected sign: the higher the cost of the regulation, the less likely it is that a pesticide is banned. The absence of cost data also reduces the likelihood that a pesticide is banned, regardless of whether the ban will reduce crop yields.

The benefits of pesticide regulation are also important in explaining which uses of a pesticide are banned and which are not. To EPA, the benefits of banning a pesticide are equivalent to the risks associated with its use, since alternatives to the pesticide are, in effect, assumed riskless. Other things equal, the greater the number of cancer cases avoided among pesticide applicators—the group with the highest average exposure—the higher the probability that a pesticide is banned. The value of a cancer case avoided among applicators is $45.58 million (1986 dollars).[13] When converted to 1989 dollars this figure—$51.51 million—is remarkably close to the value obtained from asbestos regulations, although it is estimated with less precision. [The standard error for the estimate (in 1989 dollars) is $30.22 million.]

What is perhaps surprising is that neither mixer cancer cases avoided nor dietary cancer cases avoided are significant in explaining pesticide decisions. Elsewhere [2,9] we have modified the model estimated here to include comments by affected parties (environmental advocacy groups, grower organizations) on the decision to ban a pesticide. We note that while such modifications increase the predictive power of the model, they do not alter the lack of significance of cancer cases avoided among mixer/loaders.[14] Likewise, dietary cancer cases avoided, while sometimes significant in explaining the decision to ban a pesticide, always have an implied value below $100,000.[15]

The lack of significance of cancer cases avoided among mixer/loaders can, perhaps, be explained by the large proportion of missing observations (69%) for this variable. The negligible value attached to avoiding dietary cancer cases is harder to explain. While one would expect this value to be lower than the corresponding value for applicators, based on differences in baseline risk, one would not necessarily expect the value to be so small. One possible explanation is that regulators discount estimates of dietary risk due to the conservative way in which estimates of dietary exposure are calculated. For example, EPA estimates that 200 cancer cases occur each year as a result of eating macadamia nuts sprayed with benomyl, while an additional 200 cases are caused by ingesting almonds sprayed with the fungicide. These very large numbers assume that benomyl residues will remain on the nuts at the maximum levels allowed by law, whereas, in fact, most residues disappear by the time the product is eaten.

[13] Since in Table V cancer cases avoided represent cancer cases avoided over the lifetimes of one million exposed persons, this calculation is not straightforward. See the Appendix for an explanation.

[14] Adding interest group variables also has no effect on the value of avoiding a cancer case among applicators or among consumers of dietary residues.

[15] It is interesting to note that lack of risk data for either dietary or mixer risks significantly reduces the probability that a pesticide is banned, suggesting that the ‘‘burden of proof’’ falls on EPA to prove that a health risk exists.

3.2. *Individual vs Populaton Risk*

While economists typically measure mortality benefits by the number of lives that a regulation saves, the language of environmental statutes often refers to the concept of acceptable risk—the notion that no individual should have to bear a large risk of death from any one source. Some observers of environmental regulation [10] have gone so far as to suggest that EPA balances risks and benefits in issuing regulations only if the level of risk to any one individual is below an acceptable level.

To test this hypothesis against the alternative theory that balancing occurs at all levels of individual risk—the hypothesis implicit in the probit models of Eqs. (2) and (3)—we estimated the model

$$\begin{aligned} P(\text{Ban}) &= 1 && \text{if } R_i > R_{\text{A}i} && \text{for any } i, \\ P(\text{Ban}) &= \text{Eq. (3)} && \text{if } R_{\text{A}i} < R_i && \text{for all } i, \end{aligned} \tag{4}$$

where $R_{\text{A}i}$, denotes the level of acceptable risk for group i. Equation (4) implies that a pesticide is banned for use on a particular crop if individual risk to any one group exceeds the acceptable level for that group.

Maximum likelihood estimates of Eq. (4) appear in the second column of Table V.[16] The level of acceptable risk for applicators is quite high: Only if lifetime cancer risk to applicators exceeds 1 in 100 does the model predict that a pesticide will be banned, regardless of cost. The corresponding acceptable risk levels for mixer/loaders and consumers are much lower—3 in 100,000 for mixer/loaders and 2 in 10,000 for consumers. Below acceptable risk levels, risks and benefits are both significant in explaining the likelihood that a pesticide is banned, and the implied value per applicator cancer case avoided is $47.46 million (1989 dollars).

A test of the conventional probit model against the acceptable risk model, however, indicates that the probit model cannot be rejected at either the 1 or 5% levels.[17] The notion of acceptable risk does not, therefore, provide a better explanation of pesticide regulations than a conventional probit model which assumes lives saved and regulatory costs are balanced at all levels of individual risk.

4. NATIONAL EMISSIONS STANDARDS FOR HAZARDOUS AIR POLLUTANTS

In contrast to regulations issued under TSCA and FIFRA, the National Emissions Standards for Hazardous Air Pollutants (NESHAPS) were, according to the 1970 Clean Air Act (CAA), to be set to protect human health, without considering

[16] The maximum likelihood estimator of the acceptable risk level is the lowest observed risk level above which EPA always chooses to ban a pesticide (see [2] for a proof that this maximizes the likelihood function).

[17] The likelihood ratio test statistic is 7.80. The critical value of the chi-squared distribution at the 0.05 level of significance is 7.82.

costs. Section 112 of the 1970 Clean Air Act states:

> The Administrator shall establish any such standard at the level which in his judgement provides an ample margin of safety to protect the public health from such hazardous air pollutant.[18]

As we shall see, however, EPA did consider costs in setting emissions standards for sources of air toxics, at least before 1987. In 1987 the agency was successfully sued by the Natural Resources Defense Council for that interpretation. The ruling in this case, as demonstrated below, had a pronounced effect on EPA's subsequent setting of standards for air toxics.

Section 112 of the CAA requires EPA to regulate the so-called toxic air pollutants—substances such as benzene, arsenic, asbestos, and mercury. These pollutants are not as ubiquitous as the ''criteria'' pollutants (e.g., particulates, sulfur oxides, carbon monoxide) for which EPA is to set ambient air quality standards, but are nonetheless harmful to human health. According to the 1970 CAA, EPA was first to establish a list of toxic air pollutants and then to set emissions limits for various sources of each pollutant. Between 1970 and 1990 only seven such substances were regulated—asbestos, beryllium, mercury, vinyl chloride, benzene, inorganic arsenic, and radionuclides. Five of these are carcinogens, but quantitative risk data are available for only four—vinyl chloride, benzene, inorganic arsenic, and radionuclides. It is the regulation of these substances that we examine.

Table VI lists the various sources of vinyl chloride, benzene, inorganic arsenic, and radionuclides that EPA sought to regulate. In each case, the agency considered at least one regulatory option that would reduce emissions of the toxic pollutant, as well as the option of no regulation.[19] For each option, the agency computed the cost of the option, the number of cancer cases that would occur if the option were chosen, and the post-regulation maximum individual risk (MIR). The latter measures the risk to the maximally exposed individual—the person who receives the greatest dose of pollutant from the source. For most sources of air toxics this is not a worker who is occupationally exposed, but rather a resident who lives near the source; for example, the person whose house is nearest to a copper or lead smelter.[20]

One of the distinguishing features of toxic air pollutants, as opposed to the so-called criteria (or common) air pollutants, is that they are not as widespread: They tend to pose large risks to a few individuals rather than small risks to many people. The notion of maximum individual risk captures this aspect of air toxics.

To see the importance of maximum individual risk versus population risk in the regulation of air toxics, Fig. 2 plots, for each source, the level of maximum individual risk (lifetime risk of cancer to the MEI) and annual cancer cases that would have occurred in the absence of regulation. Recall that, in the case of pesticides, a pesticide was *always* banned if dietary risk exceeded 1.7 in 10,000.

[18] Public Law No. 91-604, §112, 84 Stat. 1676, 1685 (1970).

[19] The regulatory options that EPA considers are based on specific emissions control technologies that vary significantly across substances and emissions sources.

[20] Maximum individual risk is quite different from the measure of individual risk computed in pesticide regulations. The latter is based on average rather than upon maximum exposure to the pollutant.

TABLE VI
Regulatory Alternatives for Sources of Hazardous Air Pollutants

Source	Substance	Option chosen (= 1)	Year	Maximum individual risk (×1000)	Annual cancer cases	Annual cost (mil. 89$)
Benzene transfer operations	benzene	0	90	6	1	0
		1	90	0.04	0.02	32.7
		0	90	0.007	0.009	37.06
Bulk gasoline terminals	benzene	1	90	0.05	0.12	0
		0	90	0.01	0.08	57.12
		0	90	0.006	0.08	142.8
Bulk gasoline plants	benzene	1	90	0.01	0.03	0
		0	90	0.002	0.02	38.08
		0	90	0.001	0.01	41.65
Service station storage vessels	benzene	1	90	0.005	0.13	0
		0	90	0.0002	0.06	58.31
		0	90	0.0002	0.05	238
Benzene waste operations	benzene	0	90	2	0.6	0
		1	90	0.05	0.05	98.31
Rubber tire manufacturing (ISU) benzene	benzene	1	90	0.004	0.0006	0
		0	90	0.001	0.0003	54.74
Pharmacoutical manufacturing (ISU)	benzene	1	90	0.001	0.001	0
		0	90	0.00004	0	0.13
Chemical manufacturing process vents	benzene	1	90	0.04	0.01	0
		0	90	0.01	0.008	3.33
		0	90	0.001	0.0004	46.41
Dept. of Energy (DOE) facilities	radionuclides	1	89	0.2	0.28	0
		0	89	0.1	0.25	0.2
NRC-Iicensed & Non-DOE facilities	radionuclides	1	89	0.16	0.16	0
		0	89	0.1	0.1599	2.4
Uranium fuel cycle facilities	radionuclides	1	89	0.15	0.1	0
		0	89	0.03	0.0999	31
Elemental phosphorous plants	radionuclides	0	89	0.57	0.072	0
		1	89	0.1	0.024	2.4
		0	89	0.01	0.002	22.4
Coal-fired utility boilers	radionuclides	1	89	0.025	0.4	0
		0	89	0.0001	0.2	4400
Coal-fired industrial boilers	radionuclides	1	89	0.007	0.4	0
		0	89	0.001	0.2	1700
Radon releases from DOE facilities	radionuclides	0	89	1.4	0.072	0
		1	89	0.18	0.04	1.5
		0	89	0.1	0.012	2.8

TABLE VI—*Continued*

Source	Substance	Option chosen (= 1)	Year	Maximum individual risk (×1000)	Annual cancer cases	Annual cost (mil. 89$)
Phosphogypsum stacks	radionuclides	1	89	0.091	0.95	0
		0	89	0.082	0.79	43
Underground uranium mines	radionuclides	0	89	4.4	0.79	0
		1	89	0.3	0.24	0.4
		0	89	0.1	0.09	0.8
Surface uranium mines	radionuclides	1	89	0.048	0.026	0
		0	89	0.024	0.0038	0.8
Operating uranium mill tailings	radionuclides	0	89	0.16	0.014	0
		1	89	0.09	0.009	0.5
Disposal of uranium mill tailings piles	radionuclides	1	89	0.3	0.07	0
		0	89	0.087	0.026	16
Ethylbenzene/styrene process vents	benzene	1	89	0.02	0.003	0
		0	89	0.01	0.001	0.26
Benzene storage vessels	benzene	0	89	0.13	0.071	0
		1	89	0.03	0.04	0.13
		0	89	0.03	0.03	1.67
Coke by-product recovery plants	benzene	0	89	7	2	0
		1	89	0.2	0.05	19.04
		0	89	0.2	0.03	26.18
Benzene equipment leaks	benzene	1	89	0.1	0.2	0
		0	89	0.03	0.1	89.6
Primary copper smelters	arsenic	0	86	1.3	0.38	0
		1	86	1.3	0.29	0.49
		0	86	1.2	0.2427	37.35
		0	86	1.2	0.2399	42.83
Glass manufacturing plants	arsenic	0	86	0.9	0.4	0
		1	86	0.17	0.07	4.07
		0	86	1.2	0.2307	78.69
Secondary lead plants	arsenic	1	86	0.4	0.39	0
		0	86	n.a.	0.13	18.22
Elemental phosphorous	radionuclides	1	84	1	0.058	0
		0	84	0.5	0.049	0.83
		0	84	0.1	0.023	2.92
		0	84	0.1	0.017	3.45
Coal-fired utility boilers	radionuclides	1	84	0.01	1.4	0
		0	84	n.a.	0.4	4352
Coal-fired industrial boilers	radionuclides	1	84	0.001	1	0
		0	84	n.a.	0.7	704
		0	84	n.a.	0.6	934.4

TABLE VI—*Continued*

Source	Substance	Option chosen (= 1)	Year	Maximum individual risk (×1000)	Annual cancer cases	Annual cost (mil. 89$)
Maleic anhydride plants	benzene	1	84	0.076	0.029	0
		0	84	0.011	0.025	0.75
Benzene fugitive emissions (existing)	benzene	0	82	1.46	0.45	0
		1	82	0.45	0.14	0.68
		0	82	0.42	0.126	6.32
Benzene fugitive emissions (new)	benzene	0	82	1.46	0.12	0
		1	82	0.45	0.038	0.17
		0	82	0.42	0.035	1.54
EDC/VC and PVC plants	vinyl chlonde	0	75	4.86	11	0
		1	75	n.a.	0.55	149.1

Figure 2 indicates that sources of air toxics were *never* regulated unless maximum individual risk *exceeded* 1 in 10,000. This suggests that the level of acceptable risk was considerably higher for air toxics than for pesticides.

To examine the trade off between benefits and costs in the regulation of air toxics we estimated a multinomial logit model. Specifically, we assumed that the utility of regulatory option i was a function of the reduction in cancer cases from choosing option i (rather than doing nothing), M_i, and the cost of the option (compared to doing nothing), C_i,

$$U_i = aM_i + bC_i + e_i. \tag{5}$$

In Eq. (5) e_i represents unmeasured costs and benefits of the regulatory option. The model assumes that the regulatory option is selected that yields the highest utility; thus the option with the highest U_i is selected assuming U_i is positive. If U_i is negative for all i, no regulation is undertaken.

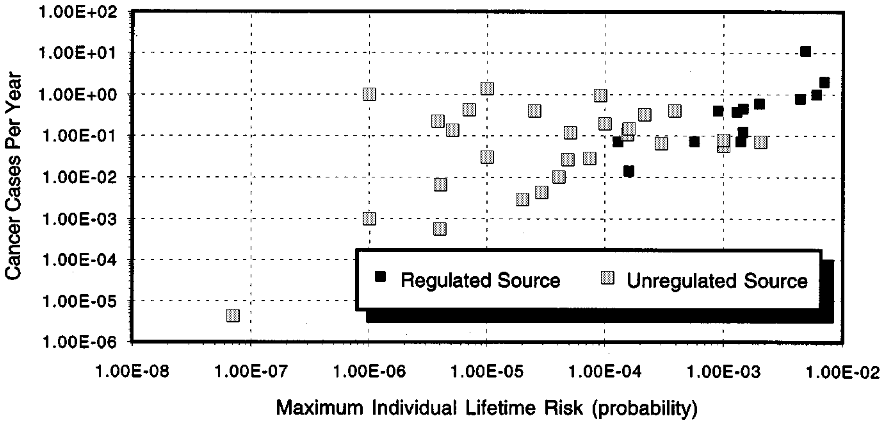

FIG. 2. Baseline risks at sources of hazardous air pollutants.

The results of estimating the multinomial logit model suggest that EPA in fact balanced cancer incidence reduction against cost. When the model is estimated using all 40 sources of air toxics (see column 1 of Table VII), the coefficients of both cancer incidence reduction and cost are significant at the 0.05 level. The implied value per cancer case avoided is, however, high—$153 million (1989 dollars).

These results, however, are somewhat misleading, as they fail to distinguish regulations issued before and after the *Vinyl Chloride* decision. In 1987, the U.S. Court of Appeals for the District of Columbia, in what has come to be known as the *Vinyl Chloride* decision,[21] ruled that EPA had improperly considered costs in setting the NESHAPS. EPA was directed to consider costs and technological feasibility only once an ‘‘acceptable risk’’ level had been achieved.

The simplest way in which to incorporate the *Vinyl Chloride* ruling into the model is to add to the utility function a term that interacts costs with a dummy variable that is equal to 1 if a regulation was issued after 1987. The effect of costs after 1987 is then the sum of the two cost coefficients. When the extra cost variable is added to the multinomial logit model (column 2 of Table VII), the level of significance of each cost variable is reduced compared to the original equation; however, both are marginally significant. The null hypothesis that the sum of the coefficients is zero, i.e., that costs were not considered after 1987, cannot be rejected at the 0.05 level.

The *Vinyl Chloride* decision thus appears to have had the intended effect on the setting of subsequent NESHAPS. To illustrate the magnitude of the effect, we note

[21] Natural Resources Defense Council, Inc. v. EPA, 824 F.2d at 1146 (1987).

TABLE VII

Factors Affecting Choice of a National Emissions Standard for Hazardous Air Pollutants

Variable name	(1)	(2)	(3)
Cancer cases avoided	9.93	21.64	21.67
	(1.87)[a]	(2.28)	(2.07)
Annual cost[b]	−0.065	−1.33	1.47
	(−2.36)	(−1.60)	(−1.96)
Annual cost* post-1987 Dummy		1.22	
		(1.53)	
Annual cost* post-1987 Dummy			1.37
*MIR > 0.0001 Dummy			(1.96)
Log likelihood	−18.84	−14.54	−11.77
Percentage of decisions correctly predicted	74.0	82.0	91.0
Implied value of a cancer case avoided[b]			
1975−1990	152.64		
	[52.07, 252.94][c]		
1975−1987		16.2	14.73
		[2.22, 30.2]	[10.6, 18.84]
1987−1990		194.06	216.70
		[123.93, 264.19]	[80.12, 353.32]

[a] Numbers in parentheses are t statistics.
[b] Millions of 1989 dollars.
[c] Numbers in brackets are endpoints of a 9% confidence interval.

that the value per cancer case avoided implied by regulations prior to 1987 is $16 million, whereas it is $194 million for regulations issued after the decision.

Allowing the *Vinyl Chloride* decision to alter the weight attached to costs does not, however, capture the acceptable risk component of the court's ruling. According to the court, costs were to be ignored only when individual risk was unacceptably high. The dummy variable interacted with costs should therefore equal 1 after 1987 only if option I would reduce maximum individual risk from a level that is unacceptably high.[22]

The effects of modifying the *Vinyl Chloride* dummy in this fashion appear in column 3 of Table VII. Statistically, the results are superior to a simple time dummy. Both cost variables, and the reduction in cancer incidence, are significantly different from zero at conventional levels. The results imply that a cancer case avoided is valued at approximately $15 million (1989 dollars) before the 1987 court decision *and the same value after* so long as maximum individual risk is below 1 in 10,000.[23] After 1987, however, if MIR was above 1 in 10,000, then EPA did not consider costs at all—the sum of the cost coefficients in column 3 is not significantly different from zero.[24]

5. CONCLUSIONS

Perhaps the most striking finding of our analysis is that, for all regulations examined, benefit and cost considerations alone explain at least 85% of the decisions issued. EPA thus behaved as though it considered benefits and costs in issuing regulations, even when costs were not to be considered in standard setting. The weights attached to benefits and costs, however, imply that EPA has been willing to have consumers and firms incur substantial costs to save one statistical life. Under the two balancing statutes—TSCA and FIFRA—the implicit value per cancer case avoided is in excess of $45 million (1989 dollars). An important question is whether members of society agree with this valuation. Compensation for the loss of one statistical life in the workplace is about one-tenth of the value implicit in the TSCA and FIFRA regulations examined here. Compensation for workplace risks, however, is for voluntary exposure to immediate risk of death. Exposure to pesticides and asbestos may not be voluntary (even for workers) if people are unaware of the risks that result from exposure.

It is also interesting to note that EPA has implicitly attached more weight to saving the lives of those who are occupationally exposed to pesticides and asbestos than to saving the lives of consumers. One reason for this may be that workers, on average, receive much larger doses of pollution than do consumers. In the case of

[22] A referee suggested that the tendency to place less weight on costs may have preceded the *Vinyl Chloride* decision. To test this, we created a dummy variable for the period 1985-86 and interacted it both with Annual Cost and with the Annual Cost* 0.0001 threshold. When these variables were added to Eq. (3) of Table VI the coefficients were not statistically significant at the 0.05 level. A similar exercise was repeated using a dummy for the period 1983–1986. Therefore, we can reject the hypothesis that the shift in EPA's behavior actually occurred before the 1987 *Vinyl Chloride* decision. Using a similar approach for the later years, we can also reject the hypothesis that the shift occurred after 1987.

[23] This is the highest of the maximum individual risk (MIR) levels that EPA itself proposed, but never officially declared, as an acceptable risk threshold (53 FR 28497 July 1988).

[24] A test of the null hypothesis that the sum of the cost coefficients in column 3 is significantly different from zero can be rejected at only the 0.11 significance level.

pesticides, for example, the median lifetime cancer risk from pesticide exposure is one in 1,000 for applicators but only one in 100 million for consumers of pesticide residues on food. On the other hand, to the extent that workers may already receive compensating wage differentials for exposure to pollution, the larger weight attached by EPA to saving their lives may not be justified.

Turning to emissions standards for hazardous air pollutants, it is interesting to note that the implied value per cancer case avoided associated with these regulations prior to 1987 is only $15 million (1989 dollars)—less than half the value implied by pesticide or asbestos regulations. After the 1987 *Vinyl Chloride* decision, however, which admonished EPA not to consider costs unless an acceptable level of risk to the MEI had been achieved, this value jumped to over $200 million (1989 dollars). This raises the question: Do balancing statutes really make a difference? Our analysis of the setting of the NESHAPS suggests that—short of recourse to the courts—prohibitions against considering costs are difficult to enforce. Likewise, Congress may require that the costs of a regulation be balanced against the benefits, but, as long as EPA has discretion in the weights it assigns to costs and benefits, regulations issued under balancing statutes may still be very costly.

APPENDIX: CALCULATION OF VALUE PER CANCER CASE AVOIDED

Equation (1) in the text implies that EPA will ban the use of asbestos in product i if the value of the cancer cases avoided (aM_i) minus the cost of the ban $(bC_i, b < 0)$ are positive,

$$aM_i + bC_i > 0. \tag{A1}$$

This is equivalent to banning asbestos in product i if the cost per life saved, C_i/M_i, falls below $-a/b$, which is the threshold value of a cancer case avoided. Computation of this threshold from the coefficients in Table II is straightforward, since the number of cancer cases avoided and the cost of the regulation enter the equation directly. For example, in Eq. (1) of Table II, $a = 4.85$ and $b = -0.099$, implying a threshold value per cancer case avoided of 48.99 million dollars.[25] The calculations in Table VII are similar.

In the case of the pesticide regulations, however, matters are more complicated. Here the measure of cancer cases avoided is the number of cancer cases avoided, *per million exposed persons, based on a lifetime of T years of exposure*, R_i. The annual number of cancer cases avoided, M_i, is related to R_i, by

$$M_i = \left(R_i \times 10^{-6}\right)/T \times \text{Size of exposed population}. \tag{A2}$$

The first term on the right-hand side of (A2) is the number of cancers per person, based on one year of exposure. Multiplying this by the size of the exposed population yields the number of cancer cases avoided per year.

To convert the coefficient of R_i in Table V to the coefficient of M_i, the coefficient of R_i must be multiplied by the inverse of the terms on the right-hand

[25] The figure in the table, 48.61 differs from 48.99 because the estimates of a and b in the table have been rounded.

side of (A2). The implicit value of a cancer case avoided is thus given by

$$-a/b = \text{Coefficient of } R_i \times 10^6 \times T/(\text{Size of exposed population})/(-b). \quad \text{(A3)}$$

For applicators, $T = 35$ and the size of the exposed population is 10,000.

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