A Damage Based Tax Mechanism for Regulation of Hazardous Waste

Thomas R. Sadler*

ABSTRACT. The Pigouvian prescription for pollution damage requires a per-unit tax equal to the monetary value of marginal external cost (MEC). However, in this tradition, few economists have proposed a damage-based mechanism to regulate hazardous waste. Using damage scores from the Waste Minimization Chemical List of the United States Environmental Protection Agency (EPA), this paper develops such an approach. Marginal tax rates correspond to environmental damage. Efficiency increases in the presence of reliable EPA damage scores, linear marginal damage, and accurate monetary values assigned to MEC (H23).

I. Introduction

This paper develops a damage-based environmental tax policy. Higher tax rates apply to the most persistent, bioaccumulative, and toxic pollutants. Depending on how well the tax rates reflect environmental damage, the externality is internalized.

For hazardous emissions, limited research exists on damage-based taxation. To regulate benzene, a major industrial pollutant, Nichols (1984) proposes a damage-based emission charge. Because of site-specific estimation, the policy would be prohibitively expensive. For chemical pollutants, Copeland (1992) develops wastewater charges. Because of the assignment of only five tax rates, the taxes do not reflect environmental damage. Fullerton (1996) finds that taxes on chemical inputs in the United States entail low rates and high compliance costs, but do not focus on environmental damage. Using an index of EPA damage values, Sadler (2000) develops a tax for chemical releases, but the EPA subsequently updated the index.

This paper adopts a Pigouvian framework; however, in two important ways, this paper differs from previous articles. In particular, (1) marginal tax rates for individual emissions reflect pollution characteristics, and (2) an entire set of pollutants is targeted. Section 2 discusses hazardous

---

*Assistant Professor, Department of Economics, Western Illinois University; email: TR-Sadler@wiu.edu; The author would like to thank two anonymous referees and an assistant editor for helpful comments on this paper.

waste and environmental damage. Section 3 models the externality. Section 4 simulates policy implementation. Section 5 concludes.

II. Hazardous Waste and Environmental Damage

The EPA regulates, with command and control policy, chemical waste streams into the water, air, and earth. The EPA mandates abatement technology, sets emission and exposure standards, and bans and restricts certain chemical production and use (McKenzie, 1994). Command-and-control regulation, however, involves excessive cost: regulators use scarce resources to obtain information that polluters already possess (Sadler, 2000).

As a result, the EPA also implements decentralized forms of policy (Fung and O'Rourke, 2000). One example, the Toxics Release Inventory (TRI), implemented as part of the 1986 Emergency Planning and Community Right-to-Know Act, requires manufacturers with 10 or more employees in SIC codes 20 through 39 to disclose chemical emission level and type. Because the EPA publishes the TRI data on-line, firms react to this public information in any manner consistent with profit maximization (Foulon et al., 2002).

As another example, in 1994 the EPA established a long-term plan to minimize chemical releases. Using 1991 as the baseline year, the goals of the plan were to reduce the use of the most persistent, bioaccumulative, and toxic (PBT) hazardous waste streams 25% by the year 2000 and 50% by 2005; to avoid transferring the waste streams across environmental media; and to encourage emission reduction at source.

In response to the plan, the EPA created the Waste Minimization Prioritization Tool, which ranks chemicals according to their PBT properties. For individual releases, a chemical score reflects both human health risk and ecological risk. Scoring data for human health risk and ecological risk vary according to degrees of magnitude, ranging from 10 to 1,000,000.

Instead of using these numbers, the EPA approximates with a logarithmic scale. Log values ranging from 1 to 6 represent two orders of magnitude. With a log scale, sub-factors become additive: scores for human health risk and ecological risk equal the sum of toxicity (T), persistence (P), and bioaccumulation (B):

$$\textit{Score for HHR Potential} = \textit{Scores for Human } T + P + B \quad (1)$$

$$\textit{Score for ER Potential} = \textit{Scores for Ecological } T + P + B \quad (2)$$

The sub-factors T, P and B assume values of 1 (low), 2 (medium), or 3 (high). Overall scores range between 6 (low) and 18 (high). Eight hundred and seventy-nine chemicals form groups by receiving the same integer score between these high and low values (US EPA, 1997).

The Waste Minimization Prioritization Tool serves as one of four criteria for the EPA's new Resource Conservation and Recovery Act PBT chemical damage list. The four criteria are the PBT score from the Waste Minimization Prioritization Tool; chemical prevalence in hazardous waste; evidence that the chemical exists in the environment at levels of concern; and the extent to which the RCRA program targets a particular chemical.

For a final ranking, the EPA converted each of the four criterion scores into a 25-point scale. The EPA then arranged each score in rank order from 1 to 100. Converted to a scale between zero and one, the damage scores are in the second column in the Appendix.

Because the chemicals are weighted by releases, the EPA scores reflect relative damage values. Therefore, these scores may be used to address the main problem of environmental taxation: the measurement of marginal damage.

III. Environmental Taxation

A representative firm's emission of one chemical is proportional to output:

$$E_i = \delta Q, \quad (3)$$

where E_i is the emission of chemical i, δ is a parameter that relates emissions to output, Q is output, and $i = 1,\ldots, n$. Environmental regulation may reduce emissions below the current level:

$$E_{ri} \leq E_i, \quad (4)$$

where E_{ri} is the emission of chemical i after regulation. Emissions lead to environmental damage: $D_i(E_i)$. Depending on atmospheric conditions and pollution synergy, marginal damage (D_i') may increase at varying rates.

A review of the Toxics Release Inventory reveals polluters that emit multiple releases. While emissions lead to varying degrees of marginal damage, synergistic effects result from chemical interaction. In certain cases, chemicals become more toxic when mixed (McKenzie, 1994). By internalizing the economic value of marginal external cost with a per-unit tax, first-best policy considers synergistic effects.

In a first-best world, regulators have perfect information and levy environmental taxes accordingly. Total private cost may be written as:

$$TPC = C_1\,(Q) + C_2\,(\delta Q - \Sigma E_{ri}\,t_i,\, Q) + \Sigma E_{ri}\,t_i, \tag{5}$$

where C_1 is production cost, C_2 is control cost (a firm's effort to reduce emissions), and t_i is a per-unit tax on chemical emission i.

After tax implementation, marginal social cost is:

$$MSC = \partial C_1/\partial Q + \delta C_{21} + C_{22} + \Sigma D_i'(dE_{ri}/dQ), \tag{6}$$

where marginal damage is defined as:

$$D_i' = \partial D_i/\partial E_i. \tag{7}$$

Firms internalize the cost of pollution in marginal private cost, a linear function:

$$MPC = \partial C_1/\partial Q + \delta C_{21} + C_{22} + \Sigma t_i(dE_{ri}/dQ). \tag{8}$$

The difference between (6) and (8), marginal external cost, is:

$$\text{MSC - MPC} = \Sigma D_i'(dE_{ri}/dQ) - \Sigma t_i(dE_{ri}/dQ) = (\Sigma D_i' - \Sigma t_i)(dE_{ri}/dQ). \tag{9}$$

To account for marginal damage, D_i', the regulator must adjust marginal private cost with t_i. Equation (9) will equal zero if the regulator has full information on the marginal damage of individual chemical releases; that is, if and only if $D_i' = t_i$, for all $i = 1,\ldots, n$.

With the following conditions, the damage-based system approximates first-best policy:

(1) Marginal damage is stable.
(2) Pollution synergy does not invalidate the EPA damage scores.
(3) Pollution damage is linear.

IV. Policy Simulation

A tax rate per emission pound for each pollutant is found by multiplying a single tax rate (t) by the damage score in the Appendix:

$$(t)(\text{Damage Score}) = \text{Tax Rate Per Emission Pound}. \tag{10}$$

For example, if t = \$1.50, a polluter would have to pay, according to the damage values in the Appendix, \$1.42 for the release of one emission pound of lead [(\$1.50)(0.944) = \$1.42] and \$1.39 for the release of one emission pound of cadmium [(\$1.50)(0.924) = \$1.39].

Baumol and Oates (1988) explain that, instead of implementing a tax equal to the value of marginal damage at the optimal level of emission reduction, the tax could reflect current net damage. Therefore, to set the tax rate, the regulator could look to ORNL and RFF (1994), which found the monetary value of lead damages, per emission pound, to equal \$32.13.

If the monetary value of damage from lead emissions equals \$32.13 per pound (damage score of 0.994), a hypothetical pollutant with a damage score of one would require a \$34.04 rate. Therefore, a tax rate (t) of \$34.04 per emission pound translates, according to equation (10), different rates per emission pound to individual pollutants. See column 3 in the Appendix.

On- and off-site emissions data from the 2003 Toxics Release Inventory were gathered at the national level, for 155 pollutants with EPA damage scores (column 4 in the Appendix). Equation (11) calculates tax revenue for individual pollutants (column 5 in the Appendix):

$$\text{Tax Revenue} = (\text{Tax Rate Per Emission Pound})(\text{TRI Emissions}). \tag{11}$$

For example, in 2003, U.S. companies emitted 731,002 emission pounds of cadmium on- and off-site. With a damage score of 0.924 and a tax rate per emission pound of \$31.45, taxation of cadmium emissions yields

$22,992,177. Without a change in production, a total emission level of 828,458,861 from all 155 toxic releases would generate $13,717,134,534.

A regulation that increases polluters' waste management costs would lead to the substitution of highly persistent, bioaccumulative, and toxic chemicals with less-harmful alternatives. The degree of substitution depends on the elasticity of pollution generation, which has been estimated for chemical solvents to be high (Sigman, 1996). Therefore, an optimistic scenario would reveal a reduction of the most problematic PBT pollutants, a reduction in total emissions recorded in the Appendix, but also a decrease in total revenue.

V. Conclusion

For individual pollutants, this paper calculates marginal tax rates per emission pound. In the presence of non-linear damage, tax rates reflect marginal external cost. With these rates, policy makers could regulate toxic releases.

Appendix

Policy Simulation: Environmental Tax Rates and Revenue

Chemical (1)	Damage Score (2)	Tax Rate/ Emission Pound (3)	Emissions in 2003 (4)	Revenue (5)
Acenaphthene	0.590	20.08	0	0
Acenaphthylene	0.514	17.50	0	0
Acetaldehyde	0.257	8.75	14,205,208	124,271,137
Acrolein	0.299	10.18	417,146	4,245,695
Acrylamide	0.340	11.57	8,925,779	103,303,396
Aldicarb	0.257	8.75	126	1,102
Allyl Alcohol	0.340	11.57	744,989	8,622,205
Aluminum	0.389	13.24	31,051,074	411,164,659
Ametryn	0.194	6.60	1,010	6,670
Anthracene	0.674	22.94	414,179	9,502,492
Antimony	0.646	21.99	1,825,939	40,152,106
Arsenic	0.736	25.05	830,425	20,805,003
Atrazine	0.278	9.46	366,409	3,467,372
Basic green 4	0.111	3.78	0	0
Benefin	0.361	12.29	0	0
Benomyl	0.382	13.00	0	0
Benzenamine, (N-(1-ethylpropyl)-3, 4-dimethyl	0.250	8.51	0	0
Benzo(g,h,i)perylene	0.590	20.08	151,767	3,048,028
Beryllium	0.583	19.85	367,297	7,289,127
Bis(2-ethyhexyl)phthalate	0.792	26.96	0	0
Bis(4-(dimethylamino)phenyl) methanone	0.167	5.68	0	0
Bromacil	0.148	5.04	0	0
Bromomethane	0.444	15.11	504,283	7,621,612
Bromoxynil Octanoate	0.250	8.51	5	43
Butyl benzyl phthalate	0.563	19.16	0	0
C.I. Disperse Yellow 3	0.167	5.68	0	0
Cadmium	0.924	31.45	731,002	22,992,177
Carbofuran	0.382	13.00	735	9,557

Policy Simulation: Environmental Tax Rates and Revenue

Chemical (1)	Damage Score (2)	Tax Rate/ Emission Pound (3)	Emissions in 2003 (4)	Revenue (5)
Chloroacetic Acid	0.278	9.46	4,281	40,512
Chloroform	0.674	22.94	1,101,490	25,271,441
Chlorothalonil	0.208	7.08	215,860	1,528,358
Chlorpyrifos methyl	0.250	8.51	0	0
Chromium	0.778	26.48	10,383,384	274,984,404
Cobalt	0.491	16.71	748,732	12,514,037
Copper	0.569	19.37	12,599,711	244,040,778
Cyanide	0.556	18.93	0	0
Dacthal	0.306	10.42	827,428	8,618,689
Decabromodiphenyl Oxide	0.292	9.94	0	0
DEF	0.278	9.46	0	0
Diazinon	0.292	9.94	43,854	435,895
Dibenzofuran	0.438	14.91	94,884	1,414,675
Dibutyl Phthalate	0.694	23.62	209,191	4,941,878
Dicofol	0.361	12.29	28	344
Diglycidal ether of Bisphenol A	0.354	12.05	0	0
Dimethoate	0.257	8.75	20	175
Di-n-octyl phthalate	0.729	24.82	0	0
Diphenylamine	0.444	15.11	488,050	7,376,271
Disulfoton	0.319	10.86	0	0
Endosulfan	0.285	9.70	0	0
Endosulfan, Alpha-	0.514	17.50	0	0
Endosulfan, beta-	0.514	17.50	0	0
Endosulfan sulfate	0.319	10.86	0	0
Ethylene dibromide (EDB)	0.403	13.72	0	0
Ethylene Oxide	0.340	11.57	463,299	5,362,037
Fluometuron	0.167	5.68	10	57
Fluoranthene	0.764	26.01	0	0
Fluorine	0.785	26.72	60,225	1,609,296
Gamma-hexachlorocyclohexane	0.674	22.94	0	0
Heptachlor	0.507	17.26	1,289	22,246
Heptachlor epoxide	0.646	21.99	0	0

Policy Simulation: Environmental Tax Rates and Revenue

Chemical (1)	Damage Score (2)	Tax Rate/ Emission Pound (3)	Emissions in 2003 (4)	Revenue (5)
Hexachlorobenzene	0.674	22.94	29,798	683,654
Hexachlorobutadiene	0.708	24.10	0	0
Hexachlorocyclohexane, alpha-	0.569	19.37	0	0
Hexachlorocyclohexane, beta-	0.569	19.37	0	0
Hexachlorocyclohexane, delta-	0.514	17.50	0	0
Hexachlorocyclo-pentadiene	0.465	15.83	0	0
Hexachloroethane	0.493	16.78	1,576	26,448
Hydrocyanic acid	0.444	15.11	597,460,628	9,029,876,541
Iodomethane	0.438	14.91	0	0
Lead	0.944	32.13	18,328,656	588,968,633
Linuron	0.167	5.68	272	1,546
Manganese	0.481	16.37	27,228,785	445,823,432
Mercury	0.190	6.47	65,212	421,765
Methoxychlor	0.618	21.04	1,056	22,215
Methylene chloride	0.590	20.08	0	0
Methyl Parathion	.340	11.57	255	2,951
Naphthalene	0.701	23.86	3,801,776	90,718,131
Nickel	0.667	22.70	5,950,917	135,113,666
Nicotinea	0.271	9.22	0	0
Nitrobenzene	0.549	18.69	298,930	5,586,392
Octane	0.194	6.60	0	0
Oxyfluorfen	0.111	3.78	0	0
Parathion	0.444	15.11	255	3,854
Pendimethalin	0.361	12.29	147,256	1,809,547
Pentachlorobenzene	0.618	21.04	1,679	35,321
Pentachloronitrobenzene	0.528	17.97	0	0
Pentachlorophenol	0.653	22.23	2,968	65,973
Phenanthrene	0.681	23.18	1,004,509	23,285,764
Phenol	0.674	22.94	8,499,213	194,997,104
Phenol, nonyl-	0.354	12.05	0	0
Phenol, 2,2-bis(1,1-dimethylethyl)	0.396	13.48	0	0
Phenol, 2,4,5-tris(1,1-dimethylethyl)	0.521	17.73	0	0

Policy Simulation: Environmental Tax Rates and Revenue

Chemical (1)	Damage Score (2)	Tax Rate/ Emission Pound (3)	Emissions in 2003 (4)	Revenue (5)
Phenol, 4-(1-methyl-1-phenylethyl)	0.438	14.91	0	0
Phenothiazine	0.194	6.60	0	0
Phenylphenol, o-	0.438	14.91	0	0
Phorate	0.424	14.43	0	0
Phosgene	0.444	15.11	18,201	275,086
Picric Acid	0.236	8.03	82,057	659,200
Pigment yellow 14	0.167	5.68	0	0
Polychlorinated Biphenyls	0.868	29.55	22,295,566	658,760,846
Polycyclic Aromatic Compounds	0.917	31.21	2,035,330	63,532,175
Polystyrene	0.278	9.46	0	0
Pyrene	0.701	23.86	0	0
Pyridine, 2-chloro-6-(trichloromethyl)	0.167	5.68	0	0
Selenium	0.576	19.61	565,634	11,090,408
Silver	0.796	27.10	191,963	5,201,399
Simazine	0.194	6.60	3,585	23,674
Terbufos	0.208	7.08	0	0
Tetrachloroethylene	0.618	21.04	3,202,893	67,378,363
Tetrachlorvinphos	0.167	5.68	772	4,389
Thiodicarb	0.292	9.94	379	3,767
Thiram	0.278	9.46	86,150	815,248
Triallate	0.292	9.94	914	9,085
Tributyltin oxide	0.111	3.78	0	0
Trichloroethylene	.618	21.04	7,175,496	150,948,900
Trifluralin	0.403	13.72	48,796	669,389
Triphenyltin Chloride	0.167	5.68	10	57
Undecane	0.194	6.60	0	0
Vanadium	0.380	12.94	1,908,095	24,681,590
Zinc	0.632	21.51	38,663,057	831,769,171
2-Methoxy-5-nitrobenzenamine	0.083	2.83	0	0
2-Methylnaphthalene	0.528	17.97	0	0

Policy Simulation: Environmental Tax Rates and Revenue

Chemical (1)	Damage Score (2)	Tax Rate/ Emission Pound (3)	Emissions in 2003 (4)	Revenue (5)
2-Methyl-4-((2-methylphenyl)azo) benzenamine	0.125	4.26	0	0
4-Bromophenyl phenyl ether	0.535	18.21	0	0
4-Chlorophenyl phenyl ether	0.361	12.29	0	0
4-(Phenylazo)benzenamine	0.167	5.68	0	0
1,1-Dichloroethane	0.563	19.16	0	0
1,2-Dichlorobenzene	0.625	21.28	92,973	1,978,001
1,2-Dichloroethane	0.542	18.45	857,993	15,829,696
1,2-Dinitrobenzene	0.167	5.68	0	0
1,3-Dichlorobenzene	0.542	18.45	1,966	36,272
1,3-Dinitrobenzene	0.382	13.00	0	0
1,4-Dichlorobenzene	0.563	19.16	96,993	1,858,824
1,4-Dinitrobenzene	0.313	10.65	0	0
2-(2'-Hydroxy-3',5'-(di-t-amyl)phenyl))benzotriazole	0.333	11.34	0	0
2,2'-Methylenebis(4-methyl-6-tert-butylphenol)	0.354	12.05	0	0
2,4-D	0.444	15.11	264,870	4,003,182
2,4-Dinitrophenol	0.486	16.54	66,735	1,104,026
2,5-Di-(1,1-dimethylpropyl)hydroquinone	0.333	11.34	0	0
2,6-Dichloro-4-nitroaniline	0.167	5.68	0	0
2,6-Di-tert-butyl-p-cresol	0.278	9.46	0	0
3,3'-Dichlorobenzidine	0.174	5.92	15	89
3,3'-Dimethyoxybenzidine	0.236	8.03	5	40
3,3'-Dimethyoxybenzidine dihydrochloride	0.167	5.68	55	313
4,4'-Methylenebisbenzenamine	0.208	7.08	0	0
4,4'-Methylenebis(2-chloroaniline)	0.382	13.00	0	0
4,4'-Methylenediphenyl isocyanate	0.167	5.68	0	0
4,4'-Oxybisbenzenamine	0.167	5.68	0	0
4,4'-Thiobis(6-tert-butyl-m-cresol)	0.167	5.68	0	0
1,1,1-Trichloroethane	0.674	22.94	117,069	2,685,909

Policy Simulation: Environmental Tax Rates and Revenue

Chemical (1)	Damage Score (2)	Tax Rate/ Emission Pound (3)	Emissions in 2003 (4)	Revenue (5)
1,2,4-Trichlorobenzene	0.667	22.70	66,589	1,511,882
2,4,5-Trichlorophenol	0.507	17.26	5,128	88,500
1,1,1,2-Tetrachloroethane	0.424	14.43	3,202	46,214
1,1,2,2-Tetrachloroethane	0.521	17.73	3,520	62,427
1,2,4,5-Tetrachlorobenzene	0.611	20.80	0	0
Total			828,458,861	13,717,134,534

References

Baumol, William J. and Oates, Wallace E. *The Theory of Environmental Policy*. 2nd Ed., Cambridge University Press, New York, 1988.

Copeland, Claudia. *Funding Water Quality Programs: Revenues for a National Clean Water Investment Corporation*. Congressional Research Service, Washington DC, July 10, 1992.

Foulon, Jerome; Lanoie, Paul and Laplante, Benoit. "Incentives for Pollution Control: Regulation or Information?" *Journal of Environmental Economics and Management*, July 2002, Vol. 44(1), pp. 169-187.

Fullerton, Don. "Why Have Separate Environmental Taxes?" in J. Poterba, ed., *Tax Policy and the Economy 10*. MIT Press, Cambridge, MA, 1996.

Fung, Archon and O'Rourke, Dara. "Reinventing Environmental Regulation from the Grassroots Up: Explaining and Expanding the Success of the Toxics Release Inventory." *Environmental Management*, 2000, Vol. 25(2), pp. 115-127.

McKenzie, Fiona. "Policy Formulation for the Management of Hazardous Pollutants." *Journal of Environmental Planning and Management*, 1994, Vol. 37(1), pp. 87-105.

Nichols, Albert L. *Targeting Economic Incentives for Environmental Protection*. The MIT Press, Cambridge, Mass., 1984.

Oak Ridge National Laboratory (ORNL) and Resources for the Future (RFF). *Estimating Externalities of Coal Fuel Cycles*. McGraw-Hill, Inc, New York, 1994.

Sadler, Thomas R. "Regulating Chemical Emissions with Risk-Based Environmental Taxation." *International Advances in Economic Research*, May 2000, Vol. 6(2), pp. 287-305.

Sigman, Hilary. "The Effects of Hazardous Waste Taxes on Waste Generation and Disposal." *Journal of Environmental Economics and Management*, March 1996, Vol. 30(2), pp.199-217.

United States Environmental Protection Agency. *Notice of Availability of Draft RCRA Waste Minimization PBT Chemical List*. Federal Register, Washington, DC, 60332-60343, 1998.

United States Environmental Protection Agency. *Waste Minimization Prioritization Tool*. EPA/530/R/97/019, U.S. Government Printing Office, Washington, DC, 1997.