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The Effects of Hazardous Waste Taxes on Waste Generation and Disposal[1]

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In 1990, 31 states levied taxes on the generation or management of hazardous waste. These taxes are one of the broadest applications of emissions taxes in U.S. environmental policy. This paper examines the impacts of the state taxes on chlorinated solvent waste from metal cleaning, using plant-level data from EPA's 1987–1990 Toxic Release Inventories. The results suggest that the amount of solvent waste generated may respond elastically to changes in incineration costs. The overall impact of state hazardous waste taxes currently in place in the United States is estimated to be small, however, because the taxes constitute a small fraction of total waste management costs. The results also suggest that the taxes successfully encourage generators to choose treatment over land disposal as their waste management method.

Like most of U.S. environmental policy, regulation of industrial hazardous waste has traditionally relied upon technology and performance standards. Recently, however, there have been calls for these policies to rely on price-based mechanisms (e.g., [10, 20]). This paper explores the efficacy of price-based policies in reducing waste by examining the empirical sensitivity of waste generation to waste management prices. Variation across states in hazardous waste taxes creates a natural experiment that is used to study demand for waste as an input into production.

The paper focuses on generation of one type of waste, spent chlorinated solvents from metal cleaning. These solvents are the most frequently generated industrial hazardous wastes in the United States [7]. Disposal of chlorinated solvents may have substantial environmental costs. The solvents are among the most common substances found migrating from Superfund sites and are considered highly toxic [15]. EPA's 1987–1990 Toxic Release Inventories provide data at the plant level on generation and off-site management of chlorinated solvent wastes.

The econometric analysis presented here suggests that firms' generation of chlorinated solvent waste is very sensitive to waste management costs. This result contrasts with simulation estimates by Wolf and Camm [22], who conclude that demand for chlorinated solvent waste management is extremely inelastic. Despite large elasticity estimates, however, my analysis predicts only a small effect of state taxes on waste generation because the taxes are low relative to total waste management costs. The econometric analysis also suggests that state taxes alter facilities' waste management choices. In particular, high taxes on disposal reduce reliance on disposal relative to treatment of wastes. However, the analysis fails to

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find a negative effect of disposal costs on waste generation comparable to the negative effect found for incineration costs.

The paper begins with a section that discusses state taxes on hazardous waste and describes earlier studies of the influence of these taxes on waste generation and management. The second section provides background on the specific group of wastes that is studied in this paper, chlorinated solvent wastes from cleaning and degreasing of metals. The third section describes the data on chlorinated solvent wastes in EPA's Toxic Release Inventory (TRI). Using these TRI data, the fourth section examines the empirical implications of hazardous waste taxes. The estimation exploits the cross-sectional and time-series variation in these taxes to examine the demand for waste generation and choice of waste management methods. Section 5 uses these estimates to predict the effect of state taxes and proposed federal taxes on total chlorinated solvent waste generation. A concluding section briefly discusses the desirability of waste-end taxes in light of the evidence presented.

1. STATE HAZARDOUS WASTE TAXES

1.1. Description of the Taxes

In 1990, 31 states funded at least part of their hazardous waste regulation or Superfund program through taxes waste generation or disposal.[2] These taxes are sometimes referred to as ''waste-end'' taxes to distinguish them from taxes on feedstock chemicals like the federal Superfund tax. Table I reports the tax rates on land disposal and incineration between 1987 and 1990.[3]

Several states levy higher taxes on land disposal than other management practices in an attempt to discourage reliance on disposal. In 1990, 8 of the 31 states with waste-end taxes levied them only on land disposal. Another 15 states taxed other management technologies, but at lower rates than land disposal. Although the taxes appear to be in the spirit of Pigouvian taxes, there is little consistency in either the relative or absolute costs the taxes established for different management activities across states.[4] The tax rates are determined based on revenue needs rather than the environmental costs of waste management.

The taxes are small in magnitude relative to the average costs of commercial waste management. An EPA survey of commercial management facilities found that 1987 incineration costs for high-energy-content liquids (including chlorinated solvents) ranged from an average low-end cost of $320 per ton and a high-end cost of $700 per ton. For comparison, the U.S. Army reports an average cost for disposal of the four solvents studied here of $708 per ton in fiscal year 1988 [14]. In 1987, the average in-state tax rate on incineration (for states with incineration taxes in place) was only $12. However, incineration costs vary substantially depend-

[2]Some states also have permit fees with tiered structures that depend on the volume of waste managed in a year. These permit fees are not discussed here because they will only affect marginal waste management costs in rare cases.

[3]An appendix with additional details on the state tax structures is available from the author upon request.

[4]Another indication that the taxes are not designed to reflect the environmental costs of waste management are the differential rates for wastes depending upon their state of origin.

TABLE I
Tax Rates on Chlorinated Solvent Wastes Generated In-State
(Dollars/Ton), 1987–1990

	1987		1988		1989		1990		Higher out-of-state?
	Land disposal	Incineration	Land disposal	Incineration	Land disposal	Incineration	Land disposal	Incineration	
Alabama	1.00	0.00	9.00	0.00	22.00	0.00	40.00	0.00	Yes
Arizona	0.00	0.00	0.00	0.00	0.00	0.00	2.00	2.00	
California	83.52	0.00	94.27	0.00	170.69	0.00	157.50	0.00	
Connecticut	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	
Delaware	12.00	2.00	12.00	2.00	12.00	2.00	12.00	2.00	
Idaho	20.00	0.00	20.00	0.00	20.00	0.00	20.00	0.00	
Illinois	7.23	2.41	7.23	2.41	14.50	4.28	17.90	5.97	
Indiana	9.50	9.50	10.50	10.50	11.50	11.50	11.50	11.50	Yes
Iowa	50.00	10.00	50.00	10.00	50.00	10.00	50.00	10.00	
Kansas	7.94	1.59	7.94	1.59	7.94	1.59	7.94	1.59	
Kentucky	12.05	1.21	12.05	1.21	12.05	1.21	24.10	12.05	
Louisiana	10.00	0.00	20.00	0.00	21.00	0.00	85.00	0.00	Yes
Maine	40.00	30.00	40.00	30.00	40.00	30.00	40.00	30.00	Yes
Michigan	0.00	0.00	0.00	0.00	10.00	0.00	10.00	0.00	
Minnesota	77.11	19.28	77.11	19.28	77.11	19.28	77.11	19.28	
Mississippi	5.00	0.00	5.00	0.00	5.00	0.00	10.00	2.00	Yes
Missouri	26.00	1.00	26.00	1.00	26.00	1.00	26.00	1.00	
Nevada	10.00	5.00	10.00	5.00	10.00	5.00	10.00	5.00	
New Hampshire	36.00	36.00	36.00	36.00	36.00	36.00	60.00	60.00	(Lower)
New York	27.00	9.00	27.00	9.00	27.00	9.00	27.00	9.00	
Ohio	9.00	2.00	9.00	2.00	9.00	2.00	9.00	2.00	Yes
Oregon	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	
Pennsylvania	0.00	0.00	0.00	0.00	16.00	9.00	16.00	9.00	
South Carolina	13.00	0.00	13.00	0.00	25.00	0.00	25.00	0.00	Yes
South Dakota	0.00	0.00	0.00	0.00	0.00	0.00	50.00	50.00	
Tennessee	5.00	2.50	5.00	2.50	5.00	2.50	5.00	2.50	
Texas	10.00	0.00	10.00	0.00	10.00	0.00	10.00	0.00	
Utah	3.00	3.00	6.00	6.00	9.00	9.00	9.00	9.00	Yes
Vermont	68.00	34.00	68.00	34.00	68.00	34.00	112.00	56.00	
West Virginia	25.24	18.93	22.71	17.03	26.01	19.51	35.29	26.47	
Wisconsin	0.30	0.00	0.30	0.00	0.50	0.00	0.50	0.00	

Source. Compiled from California State Board of Equalization (1988) and state statutes and regulations.

Note. Final column reports whether the state has higher tax rates for wastes imported for treatment or disposal.

ing on the characteristics of the waste. Thus, for some firms with particularly clean wastes, the taxes may represent a significant share of incineration costs.

Taxes were a more significant share of land disposal costs than incineration costs. According to the EPA survey, commercial land disposal costs ranged from $97 to $166 per ton in 1987. By comparison, the mean land disposal tax rate in states with such a tax in place was $22 per ton in 1987.

1.2. Earlier Empirical Studies of Waste-End Taxes

Despite the low levels of these taxes, several previous studies suggest that they may alter generators' behavior. Two studies examine experience with individual state waste-end taxes. Deyle and Bretschneider [4] examine changes in waste management in New York state following a 1985 increase in New York's waste-end taxes. Although they observe about a 10% decline in hazardous waste management, several other significant policy shifts might also have contributed to the decline. Similarly, Reams *et al*. [18] examine annual data on imports of waste into Louisiana from 1986 through 1992, during which time the tax rates increased twice. Louisiana's imports of hazardous waste fell during this period, leading the authors to conclude that the taxes deterred waste imports, but other influences on imports may have also have contributed to the decline.

Two engineering studies from the mid-1980s also suggest that the state taxes may have discernible effects on hazardous waste management. Table II presents a summary of results of studies by the CBO and EPA. The CBO [2, 3] studied two tax policies that resemble current state taxes. One CBO policy taxes landfilling and underground injection exclusively, while the second also taxes destructive treatment and recycling but at lower rates than land disposal. The EPA [5] examined tax policies that charge for landfilling, underground injection, and surface impoundments, but not for treatment and recycling.

In both the CBO and EPA studies, the taxes redistribute a fixed amount of wastes among different management practices. EPA's model relies on a linear programming approach based on on-site and commercial waste management cost functions produced by engineers. Unlike the EPA, the CBO does not base its estimates on cost functions. Instead, the CBO study uses a detailed prediction of the initial distribution of management methods and fairly *ad hoc* assumptions about the total waste that will change management methods with any change in

TABLE II

Engineering Estimates of the Effects of Waste-End Taxes, by Management Method

	CBO Analysis		EPA Analysis			
Management method	Policy 1	Policy 2	Policy 1	Policy 2	Policy 3	Policy 4
			Tax rates per ton			
Land disposal—no pretreatment	$22.69	$16.29	$4.54	$19.96	$45.37	$154.26
Land disposal—with pretreatment	$4.54	$16.29	$4.54	$19.96	$45.37	$154.26
Underground injection	$3.63	$2.72	$4.54	$19.96	$45.37	$154.26
Incineration, recycling, reuse	0	$2.72	0	0	0	0
			Percent change over baseline after 5 years			
Landfill—total	−44.1	−52.9	−6.1	−61.5	−62.5	−63.1
Landfill—no pretreatment	0	+6.8	—	—	—	—
Landfill—with pretreatment	−58.9	−68.4	—	—	—	—
Underground injection	−6.3	−14.7	−24.1	−50.5	−100	−100
Surface impoundment—storage	—	—	−67.3	−87.9	−91.5	−99.8
Surface impoundment—disposal	−9.3	−9.3	−3.4	−4.4	−8.1	−99.2
Incineration	0	−6.7	—	—	—	—
Chemical treatment	+171.9	+33.3	—	—	—	—
Land treatment	−79.1	−85.4	—	—	—	—
Reuse as fuel	+8.9	+1.1	—	—	—	—
Recycling/material recovery	+140.6	+71.0	—	—	—	—
Discharge to sewers or water	+32.4	+94.2	—	—	—	—

Source. Author's calculations based on results in [2] and [5]. The EPA study does not provide information on the alternatives to land disposal and surface impoundment.

relative prices. Both studies suggest that state taxes in the late 1980s may have a measurable impact on waste management: by 1987, 10 states' taxes exceeded the level of the second EPA tax in Table II, at which level the EPA predicts a 60% reduction in the use of land disposal.[5]

2. CHLORINATED SOLVENT WASTE

This paper examines the effect of state hazardous waste taxes on the generation and management of a single group of wastes—spent chlorinated solvent from metal parts cleaning. Four chemicals that make up the bulk of chlorinated solvents used for metal cleaning are studied: trichloroethylene (TCE), 1,1,1-trichloroethane (TCA), perchloroethylene (PERC), and methylene chloride (METH).[6]

2.1. *Generation of Solvent Waste*

The technology for cleaning metals with chlorinated solvents for metal cleaning is similar across industries [17, 22]. Two types of technologies account for most use of the solvents. Cold cleaning uses the solvents in liquid form at room temperature to remove contaminants including drawing compounds, cutting and grinding fluids, polishing and buffing compounds, and miscellaneous contaminants like metal chips. The solvent may be applied by spraying the object or immersing it in a bath. A second metal cleaning technique is vapor degreasing, in which heated solvent condenses on the object and cleanses it.

Hazardous wastes from metal cleaning may be generated in the form of sludge that accumulates in the bottom of a bath, solvent that becomes too contaminated to use, and still bottoms from distillation of solvents for reuse. These processes are an important source of industrial hazardous waste in the United States. According to a 1986 survey, 17% of large hazardous waste generators had some wastes from vapor degreasing and 17% from other types cleaning and degreasing, making these the two most frequent waste-generating activities [7].

Firms have considerable flexibility in the amount of these wastes to generate. Waste generation may be reduced by process changes that slow the time until the solvent becomes too contaminated to use. For example, solvent lifetimes may be prolonged by changing the way parts are handled prior to cleaning or by running parts through an earlier rinse with less pure solvents. The plant may also introduce measures to increase the cleaning efficiency of solvent baths or sprays, for example, by combining them with mechanical agitation. Finally, organic solvents may be replaced with aqueous cleaners or with mechanical cleaning methods. This flexibility may explain the high price elasticities estimated in Section 4.

[5]The CBO and EPA taxes apply to all wastes generated, while most states restrict their taxation to waste managed off-site only. Different kinds of wastes are managed on-site than off-site, so these studies should not be regarded as predicting the effects of state taxes directly.

[6]Smaller amounts of TCA are used for electronic circuit-board defluxing and of METH for paint stripping. Further, METH may be used in a non-solvent application in the manufacture of photographic film, and for this reason, all observations in SIC 3861 (photographic equipment and supplies) are excluded from the sample in the next section.

2.2. *Management of Solvent Waste*

Because these solvents are generated in relatively moderate quantities by a large number of plants, virtually all waste that is not recycled is managed off-site by commercial facilities.[7] There are several options for chlorinated solvent waste management. Chlorinated solvents have relatively high BTU value and may be incinerated or blended with other materials and reused as fuel in industrial boilers. Spent solvents may also be landfilled, typically in 55-gallon drums to reduce their mobility. In addition, many facilities recycle these solvents either on- or off-site. Data from waste manifests in California indicate that 69% of halogenated solvents shipped off-site in 1987 were recycled [16]. After recycling, purified solvents return to cleaning applications.

Table III shows the waste management practices used by the facilities in Toxic Release Inventory sample analyzed in the next section. Incineration led all other management methods, accounting for 42% of shipments and 37% of the waste in the final year. Its relative importance grew over time, but the absolute amount incinerated remained stable.

Land disposal was used infrequently, accounting for 4% of the total shipments and 2% of the total wastes in 1987. Land disposal was severely restricted by federal

TABLE III

Waste Management Methods Used for Chlorinated Solvent Wastes, 1987–1990

	1987 Percent of:		1988 Percent of:		1989 Percent of:		1990 Percent of:	
	Shipments	Waste	Shipments	Waste	Shipments	Waste	Shipments	Waste
Disposal								
Landfill/land treatment	4.4	1.9	4.2	1.7	3.6	0.8	3.6	0.8
Underground injection	0.1	0.1	0.4	0.1	0.4	0.2	0.5	0.0
Other disposal	5.7	6.8	4.9	9.1	5.0	8.2	5.1	10.5
Treatment								
Incineration	20.5	16.8	35.3	28.1	40.5	33.8	42.2	37.3
Stabilization	0.8	0.2	0.5	0.2	0.4	0.2	0.7	0.2
Wastewater treatment	0.8	0.6	0.5	0.1	0.6	0.3	1.4	0.8
Other treatment	19.4	26.0	16.7	25.3	14.4	21.8	13.2	20.8
Other								
Reuse as fuel	8.9	8.3	2.1	2.1	1.1	1.6	0.2	0.1
Temporary storage	3.4	2.8	3.0	2.7	2.5	3.7	2.6	2.6
Transfer to waste broker	7.0	7.0	7.6	13.0	8.0	11.8	7.8	12.3
Unknown	29.1	29.2	24.7	17.6	23.5	18.6	22.7	14.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total number of shipments	2758	—	2569	—	2299	—	2063	—
Total quantity of waste (tons)	—	19,693	—	13,571	—	10,846	—	7,470

Source. Author's calculations based on 1987–1990 Toxic Release Inventories. A "shipment" is a generator–management facility pair.

[7] This reliance on commercial disposal was one reason for choosing to study this group of wastes. Commercial costs are more likely to be uniform across firms than non-commercial alternatives and hence provide a somewhat cleaner experiment. In addition, fewer states tax on-site management than off-site management.

regulations imposed in November 1986. Continued reliance on land disposal in the sample may be attributable to exemptions from the regulatory prohibitions for small-quantity waste generators and low-concentration solvent wastes. Although it is not possible to identify whether generators in the TRI qualified as small-quantity generators, land disposal was more frequent among plants that generated small quantities of chlorinated solvent wastes.[8] Surprisingly, however, reliance on land disposal does not much decrease between 1988 and 1989 when the small-quantity generator exemption and exemptions for low-concentration waste expired. In 1989 and 1990, continued use of land disposal may be from very-small-quantity generators (who are not subject to federal regulation), plants that use these chemicals in nonsolvent applications, or those not in compliance with regulations.[9]

Table III shows evidence of a fairly dramatic decline in the amount of spent solvent waste generated over the period 1987–1990. At least two factors may account for this decline.[10] First, the cost of commercial treatment may have increased because of stricter RCRA regulations on management facilities after 1984. The land disposal restriction may also have contributed to increased costs by expanding demand for existing treatment capacity. Second, some of the decline may be specious. Formal and informal pressures to reduce waste may have encouraged some overreporting of releases in the earliest years of the program; ‘‘corrections’’ submitted after the reporting year have increased average disposal per facility with each subsequent release of the data.

3. TRI DATA ON CHLORINATED SOLVENTS

The data on generation and disposal of chlorinated solvent waste that are used in Section 4 are derived from EPA’s Toxic Release Inventory (TRI). Congress began TRI as part of a ‘‘community right-to-know’’ program to make information about toxic chemicals available to local organizations. Beginning in 1987, manufacturing plants that use prescribed quantities of any of over 300 chemicals must file reports.

TRI requests information about the amount of the chemical released or transferred off-site. These quantities differ from the RCRA definition of the quantity of hazardous waste, which includes the amount of contaminated media as well as the toxic chemical. This difference poses a difficulty for the purposes of this paper because it is not possible to segregate large- and small-quantity generators according the RCRA definitions and thus identify the group for which land disposal was

[8] TRI does not provide enough information to distinguish SQGs from other plants because it reports the amount of the toxic chemicals rather than the amount of waste.

[9] In 1989, land disposal was used by 2.6% of plants that generated more than 1200 kg of chlorinated solvent per year (and therefore were definitely not exempted from the restriction based upon size). The rate among the remaining plants was 7.4%.

[10] The decline from 1987 to 1988 may be somewhat spurious because of confusion over reporting requirements. In particular, although TRI does not require reporting of recycling and reuse, a code for ‘‘reuse as fuel’’ is deceptively provided in the documentation for the TRI forms. Especially at the outset, this code tricked some facilities into reporting these quantities. In the empirical analysis, these observations are treated as zero for consistency with those firms that understood the requirements.

legal in 1987 and 1988.[11] But, the TRI values may have the advantage that they are more closely related to environmental damages than the RCRA quantities.

The data used in the next section are taken from the 1987 (the first year of the inventory) through 1990 Toxic Release Inventories. Only facilities in SICs 33–38 are included in order to focus on metal cleaning applications. The facilities in the sample are spread broadly across these industries, with the largest number in metal fabrication, SIC 34 (32% of facilities in 1990), and electrical equipment and electronics, SIC 36 (20% of facilities in 1990). There are 6138 annual reports by facilities that indicated positive waste generation of at least one of these chemicals; these reports are the basis of the empirical analysis in the next section.

4. EMPIRICAL ANALYSIS OF WASTE MANAGEMENT

This section studies the sensitivity of chlorinated solvent waste generation to disposal costs, using state taxes as the principal indicator of cost variation. It begins with a simple model of waste generation to guide the estimation. Then, empirical estimates are presented. The first set of estimation results identifies changes in the cost of waste disposal by time-series and cross-sectional variation. However, because many components of waste disposal costs are not observed, the next set of estimates exploits the panel structure to estimate the parameters with fixed facility-specific effects.

Initially, incineration costs are the basis for the price of waste generation in the estimated equations. Incineration accounts for most of the wastes whose management method is classified. In most states, the same tax rates apply to incineration as other forms of treatment, so these tax rates are appropriate for all treated wastes. Later in the section, the basic derived-demand model is extended to allow generators to choose waste management methods as well as quantities.

4.1. An Empirical Model of Demand for Waste Management

Chlorinated solvent wastes may be regarded as a production input. Waste-generating firms minimize their costs subject to a production function that includes not only conventional inputs such labor and capital but also waste. Because chlorinated solvent wastes are managed at commercial facilities, the factor price is the price of these waste management services. A firm that relies on four traditional inputs—labor L, capital K, energy E, and materials M—in addition to waste W to produce output Q would solve

$$\min P_L L + P_K K + P_E E + P_M M + P_W W$$
$$\text{s.t. } Q = f_s(L, K, E, M, W),$$

where $f_s(L, K, E, M, W)$ represents the production function for a firm in industry s. If all industries' production functions are Cobb–Douglas with common factor

[11] Further, with exception of Texas, states base their taxes on waste including its medium. Thus, one possible response to waste-end taxes is to increase the concentration of wastes. The TRI data will not allow detection of these responses, only reduction in toxic substances. The difference between Texas and other states rates creates an inconsistency in the empirical work; however, the results were not sensitive to exclusion of the Texas observations.

shares, then demand for waste for firm i would be

$$\log W_i = (\log \alpha_W + \gamma_s) + \log Q_i + \sum_{j \in \{L, K, E, M\}} \alpha_j \log P_{ji} + (\alpha_W - 1)\log P_{Wi} + u_i, \quad (1)$$

with $\sum_j \alpha_j = 1$ and $\alpha_j \geq 0$ for $j \in \{L, K, E, M, W\}$. Terms in the intercept, γ_s, vary by industry and chemical.[12]

Variables. The most important problem in applying Eq. (1) is that direct evidence about P_W is not available. Several approaches are taken to represent P_W in the empirical work that follows. In the first few equations, the incineration tax rate in the state is the principal source of variation in these costs. For these estimates, P_W in Eq. (1) equals the tax for incineration of in-state wastes plus midrange incineration costs.[13]

Subsequently, a few variables are added to this basic equation to capture other sources of variation in waste management costs. Interstate shipment of waste is widespread: only 49% of the waste was managed in the state it was generated. Thus, the tax rate in the generating state does not give a complete description of the relative tax costs of generating waste in one state versus others. In some of the equations, a weighted average of tax rates in all other states represent out-of-state options. The average weights out-of-state rates in other states based on their proximity to the generator's state.

The equations also attempt to capture other variation in state hazardous waste policies that might confound the coefficient on the in-state tax rate. Although the 1984 amendments to RCRA essentially brought federal standards up to the level of the most stringent state treatment and disposal standards, state policies may vary in other dimensions. First, communities may be more successful in blocking installation of waste treatment capacity in some areas than others [12]. To account for geographical variation in the availability of waste management services, capacity for liquid incineration in the state is included among the predictors of waste generation. The capacity variables are EPA's 1987 projection of commercial capacity available in each state by 1990 [6].[14] In the long-run, this capacity variable may also respond to tax rates. However, the technological and political hurdles in siting new waste management capacity make entry of permitted facilities a very slow process. Most of states adopted waste-end taxes in the early or mid-1980s, making it unlikely that the distribution of waste management capacity has adjusted within the sample period.

A second measure of cost variation is the number of auxiliary state waste management policies in the late 1980s [11]. States receive points for right-to-know

[12] Chlorinated solvents are used in a similar manner across a wide variety of industries, so there is reason to believe that demand for solvent waste and substitution of these wastes for other inputs may be characterized by the same parameters across industries.

[13] These costs are estimated at \$659 per ton, the midpoint between the EPA estimate of \$510 per ton as mid-range costs for high BTU wastes and the Army report of \$708 per ton costs for chlorinated solvent management.

[14] Several major facilities withheld their capability data from this inventory as confidential business information. When commercial facilities were listed in a state in EPA's *Directory of Commercial Hazardous Waste Management Facilities*, but reported capacity was zero in [6], facilities in that state were attributed the average facility capacity.

programs (similar to TRI), voluntary toxic substance reduction programs, and reporting requirements for waste transportation. The state scores range from zero for Arkansas to 8 for California, Oregon, and Washington. All the variables measuring costs are assumed to be related to P_W in a log–log manner.[15] The assumption permits the estimated version of Eq. (1) to be linear in all parameters.

In addition to these measures of waste management costs, estimating Eq. (1) also requires measure of output, Q, and other input prices. Unfortunately, TRI provides no measures of the plants' output. In the estimated equations, output is measured by the average value of shipments for facilities in the plants county and industry from the 1987 Census of Manufactures. The variable is only available for some of the observations, reducing the sample from 6138 annual reports to 3486.[16]

The input prices that are included in the estimated equation are wages and energy prices. The wage variable is the average hourly cost per production worker, derived from the same match with the 1987 Census of Manufactures as above. The energy costs, P_E, are annual total industrial energy cost per million BTU by state and year.[17] Although the theory calls for inclusion of other input prices, particularly capital and material costs, data were not available to make this possible. Dummy variables for the plant's two-digit industry and the year are also included in the equations, as well as variables to indicate the chemicals involved.

Pooled estimates. Table IV implements the model above, using both cross-sectional and time-series variation in the incineration tax rates. The coefficients on the tax rate in the state of generation suggest that waste generation is very sensitive to treatment costs. In the first column of the table, the point estimate of this elasticity is -9.2 and is significantly different from zero at the 5% level.

In column 1, the facility's output is included in the equation but no input prices. Although the coefficient on output is positive as expected, the output coefficient is not statistically different from zero. The lack of precision in this coefficient estimate may result from noise in this variable because the variable used is average output for the county rather than the specific plant.

The second column adds input prices, specifically wages and energy prices, to the equation. It is not possible to reject the hypothesis that the coefficients on wages and energy prices equal zero in any of the equations.[18] These results suggest the absence of much substitution between waste and conventional inputs, shedding

[15] From a theoretical perspective, there is no reason to prefer this specification to others, such as a linear relationship. The log–log form was chosen in order not to complicate arbitrarily the estimation. A version of the equation was estimated with a linear relationship between P_W and the various cost variables (making the estimated equation non-linear in parameters). The price elasticity of generation was -9.17 (2.04), within the range of the linear-in-parameters estimates presented in Table IV.

[16] When the Census reported data at the four-digit or three-digit SIC for the county, these data were used, otherwise the data were matched at the two-digit SIC level for each county. For many facilities, data could not be matched even at this level of detail because of Census confidentiality restrictions and because many facilities appear to report different SIC codes to the TRI than the Census. The restriction on the sample tends to increase the representation of facilities in more densely industrialized areas. When the full sample is used, the point estimate for the elasticity with respect to the incineration tax is lower than the estimate in column 1 of Table I.

[17] These data are from the Energy Information Agency's *State Energy Price and Expenditure Report*.

[18] An alternative measure of wages, manufacturing wages by state and year from the Bureau of Labor Statistics *State Employment and Earnings*, also yields statistically insignificant coefficients.

TABLE IV
Estimates of Demand for Waste Generation

	Dependent variable: Log (waste generation)					
	No facility fixed effects				With facility fixed effects	
	(1)	(2)	(3)	(4)	(5)	(6)
Log (tax on incineration)	−9.21** (3.08)	−8.81** (3.13)	−16.36** (5.28)	−22.07** (5.64)	−7.19** (3.62)	−7.83** (3.63)
Log (out-of-state incineration tax)	—	—	−3.90** (1.67)	−5.09** (1.71)	—	−0.826** (0.291)
Log (incineration capacity)	—	—	—	−0.004 (0.007)	—	—
Log (legislative measures)	—	—	—	−0.323** (0.087)	—	—
Log (value of shipments)	0.064 (0.042)	0.062 (0.050)	0.063 (0.050)	0.035 (0.051)	—	—
Log (wage)	—	−0.001 (0.193)	−0.02 (0.19)	0.07 (0.20)	—	—
Log (industrial energy price)	—	−0.07 (0.16)	0.03 (0.16)	0.21 (0.17)	—	—
N	3486	3486	3486	3486	7230	7230
R-squared	0.029	0.029	0.030	0.034	0.59	0.59

Note. Standard errors in parentheses. Heteroskedasticity-robust s.e. in columns 1−4. Dummies for the chemicals and year are also included in the equations. Columns 1−4 include dummies for 6 two-digit industries. Columns 5 and 6 add facility-specific fixed effects.

**Statistically significant at 5%.

doubt on the assumption of a Cobb−Douglas production function.[19] Another possible misspecification is the restriction that all firms in six different industries have the same α parameters. When the equation in column 3 was run separately by industry, however, the coefficients on output, wages, and energy prices remain statistically insignificant with approximately the same point estimates.[20]

Columns 3 and 4 of Table IV broaden the variables used to reflect waste management costs. In column 3, other states' taxes on incineration are included. As described above, the variable is based on 47 states' rates for out-of-state waste weighted by the geographic proximity of each state. The variable enters with a coefficient of −3.9 that is statistically significant. It suggests a substantial impact of out-of-state taxes on generation.

Column 4 adds two further measures of the cost of waste management. Incineration capacity in the generator's state may reflect a combination of transportation costs and public policies that restrict facility siting. The coefficient on this variable does not have the expected sign but is not significantly different from zero. The

[19] The fact that the coefficient on output is less than one also weakens the case for a Cobb-Douglas representation. Further research will be necessary to determine the nature of this production function more accurately. For example, it might be desirable to estimate a translog cost function if it were possible to assemble more complete data on cost shares for these facilities.

[20] When the equation was run separately by industry, the coefficients on taxes were statistically significant at the 10% level only for SIC 35 (Industrial machinery) and 36 (Electrical and electronic equipment). Their coefficients, respectively, were −11.9 (6.9) and −21.6 (4.8).

second cost measure, a count of the number of state hazardous waste policies in the late 1980s, does appear to predict the extent of waste generation. The magnitude of this coefficient would indicate that a plant would generate twice as much waste in the least active state as in the most active states. The in-state tax coefficient remains negative and statistically significant with the inclusion of these additional policy variables.

Fixed-effects estimates. The second group of estimates in Table IV permit facility-specific fixed effects in the demand equation. This type of model has two significant advantages over the previous models. First, allowing fixed effects will capture many facility-specific sources of cost variation (such as differing transport costs) as well as state-level variation in management costs. With fixed effects, omitted policy variables should not bias the tax coefficients, unless states alter their regulatory programs at the same time as increasing their tax rates. In practice, increases in state waste-end taxes appear to correspond more with changes in budgetary needs than with reforms of hazardous waste policies. Second, the fixed-effects model alleviates some of the difficulties in finding suitable measures of plant output and input prices.

For the fixed-effects estimates, the sample has been restricted to facilities which are present in at least 3 years and generated positive quantities of waste in at least 1 year. No variation in output or wages is available across time, so output and input prices are not included. Year-specific effects are allowed in addition to the facility-specific effects. The equations continue to include dummies for each chemical.

The first fixed-effects equation (in column 5 of Table IV) includes only in-state tax rates. It yields a statistically significant coefficient on incineration taxes with an elasticity of -7.2. In column 6, the second equation explores the effect of other states' taxes in the fixed effects equations. Again, both coefficients are statistically different from zero with the expected sign.

In both fixed-effects equations, the point estimates on tax variables are lower than those obtained from the earlier equations. Lower elasticities might be expected if the fixed-effects estimates capture a short-run elasticity, while the cross-sectional variation that helps identify the pooled estimates produces a longer-run elasticity. As the earlier discussion of chlorinated solvents indicated, plants may reduce their generation of these wastes through simple housekeeping changes that may be accomplished rapidly. They may also move to more advanced degreasing machines or alternative cleaning methods. These options suggest that one might expect to see both an immediate response to changes in the tax rate and an even greater long-run response.[21]

4.2. Choice of Management Methods

The previous equations assume that all chlorinated solvents are incinerated or thermally treated. In fact, some firms choose other waste management methods. This section examines the choice among management methods. Unfortunately, the Toxic Release Inventory does not permit differentiation between many methods

[21] The hypothesis that there is a delayed response to the tax rates was tested directly by including lagged tax rates in the equation in column (2). The coefficient on the first lag was -2.82 (standard error 0.76) and -9.02 (3.33) on the contemporaneous tax rate.

because most facilities code their management method in an ambiguous manner such as ‘‘other’’ or ‘‘unknown.’’ For this reason, the analysis focuses on two broadly drawn categories of management, treatment (including principally ‘‘incineration’’ and ‘‘other treatment’’) and disposal (mostly ‘‘land disposal’’ and ‘‘other disposal.’’) Table III shows the breakdown of management method used by TRI facilities.

The determinants of the choice between disposal and treatment are examined using a probit model in Table V. Although neither method’s cost is observed directly, the variables that were used above as indicators of management costs may be used in this equation. First, firms face differing in-state tax rates on the management methods. Tax rates on land disposal apply to other kinds of disposal such as surface impoundment in most states. Similarly, tax rates on incineration usually apply to all kinds of treatment and would tend to encourage reliance on this management method relative to disposal. Later columns include out-of-state rates, management capacity in state, and hazardous waste measures as before. Dummies for the chemical and year are included because these may help determine the relative costs of the two alternatives. The sample is reduced to facilities that relied on treatment or disposal. It is unclear what costs to associate with records where the management method was labeled as ‘‘other’’ or ‘‘unknown,’’ so these observations are excluded. For the probit, the observations are weighted by the amount of waste that the facility generated.

The first column in Table V includes only the two in-state tax rate variables. In this first equation, the results suggest a role for states’ land disposal taxes in reducing disposal. Incineration taxes may have the opposite effect, but the coefficient on these taxes is not significantly different than zero. In the second column, out-of-state tax rates provide a more complete picture of the variation in waste management costs created by state waste-end taxes. Both out-of-state tax rates enter with the expected sign. The inclusion of these tax rates substantially increases the magnitude of the coefficients on in-state tax rates and renders the in-state rate on incineration statistically significant.

The last two columns in Table V add nontax sources of variation to the equations. First, capacity for land disposal and treatment of liquids is added. Land disposal capacity in the state does seem to increase the frequency of reliance on this management method. Treatment capacity is not as successful; it enters with the wrong sign but is not statistically different from zero. Finally, inclusion of the number of legislative programs in column 4 of Table V yields the surprising result that more legislatively active states have more disposal. Many of the most active states are located in the West, where sparsely populated areas may give rise to lower land disposal costs. Thus, the apparent failure of active states to discourage land disposal may be the result of a spurious correlation.

4.3. Waste Generation with Management Selection

This subsection uses a model that integrates the management selection decision with the choice of the amount of how much waste to generate. Use of treatment and disposal appear to be perfect substitutes; 99% of the plants in the sample relied exclusively on one of the methods.[22] A facility may select the minimum cost

[22]A single facility may generate chlorinated solvent wastes with varying levels of purity and hence different treatment costs. Thus, some facilities may use multiple management methods in the presence of perfect substitution between treatment and disposal.

TABLE V
Probit Estimates for Choice of Management Method

	Dependent variable: 1 if disposal used			
	(1)	(2)	(3)	(4)
Tax on disposal	−0.00245**	−0.0156**	−0.0201**	−0.0218**
	(0.00085)	(0.0071)	(0.0073)	(0.0073)
Tax on incineration	0.00422	0.0335**	0.0397**	0.0430**
	(0.00369)	(0.0088)	(0.0092)	(0.0093)
Out-of-state disposal taxes	—	−0.649**	−0.726**	−0.772**
		(0.338)	(0.340)	(0.341)
Out-of-state incineration taxes	—	1.89**	1.92**	2.07**
		(0.47)	(0.47)	(0.47)
Land disposal capacity	—	—	0.0323**	0.0212**
			(0.0169)	(0.0172)
Treatment capacity	—	—	0.358	0.768
			(0.431)	(0.448)
Legislative measures	—	—	—	0.0543**
				(0.0159)
1988	0.04	0.29	0.35*	0.38*
	(0.07)	(0.21)	(0.21)	(0.21)
1989	−0.21**	1.30	1.58	1.69
	(0.07)	(1.11)	(1.08)	(1.09)
1990	−0.03	1.38	2.01	2.06
	(0.08)	(2.38)	(2.40)	(2.40)
N	3486	3486	3486	3486

Note. Standard errors in parentheses. Dummies for each chemical are also included in all equations; 1987 is the excluded year.

*Significant at 10%.

**Significant at 5%.

management method and then base its decision about the amount of waste to generate on the price of this least-cost management method.[23] Thus, the waste generation decision could takes the form

$$\log W_i = (\log \alpha_W + \gamma_s) + \log Q_i + \sum_{j \in \{L, K, M, E\}} \alpha_j \log P_{ji} + (\alpha_W - 1)\log\left(\min\left(P^{\mathrm{T}}_{W_i}, P^{\mathrm{D}}_{W_i}\right)\right) + u_i, \tag{2}$$

where $P^{\mathrm{T}}_{W_i}$ and $P^{\mathrm{D}}_{W_i}$ are the prices of treatment and disposal, respectively, for observation i.

If the price of the chosen option could be observed directly for each plant, a single-stage procedure would sufficient to estimate Eq. (2). The relevant P_W could simply be substituted for each observation. With prices that are not observed directly, however, the selection of management method may provide additional

[23] Because the two waste management methods appear to be perfect substitutes, the model differs from conventional two-stage production decisions studied extensively in the energy literature (e.g., [9]). In these energy models, the first stage determines a composite price for related inputs, while in this model only a single price is relevant.

information about the price. For example, the fact that disposal is chosen by some firm may indicate that it experiences a lower disposal price than expected given its attributes. Thus, the choice of management method may influence the expected error in the generation decision. With certain assumptions, this problem can be corrected by inclusion of an inverse Mills ratio selection term in the generation equation.

Suppose the disposal price depends on observed variables according to a general functional form

$$\log P_{W_i}^{\mathrm{D}} = f_{\mathrm{D}}\left(\tau_{\mathrm{D}_i}, X_{\mathrm{D}_i}\right) + \epsilon_{\mathrm{D}_i} \tag{3}$$

where τ_{D} is the tax on disposal and X_{D_i} is a vector of other variables that contribute to the cost of disposal. An analogous expression characterizes treatment:

$$\log P_{W_i}^{\mathrm{T}} = f_{\mathrm{T}}\left(\tau_{\mathrm{T}_i}, X_{\mathrm{T}_i}\right) + \epsilon_{\mathrm{T}_i}. \tag{4}$$

Disposal is chosen if $P_{W_i}^{\mathrm{D}} \leq P_{W_i}^{\mathrm{T}}$ and treatment otherwise. This decision can be estimated using a probit specification if the two errors, ϵ_{D_i} and ϵ_{T_i}, are independent and normally distributed.[24] This probit model forms the basis for the calculating an inverse Mills ratio selection term. For consistency with the equations in Table IV, the independent variables in the probit are in logs.

The results of two specifications for Eqs. (2) through (4) are presented in Table VI. In the first three columns, only in-state tax rates are relevant to the management prices. In the second three columns, out-of-state tax rates are added as a determinant of prices. Columns 1 and 4 present probit estimates that are the basis for the selection terms for each of the two specifications. Columns 2–3 and 5–6 show the estimates of Eq. (2) for the two specifications. Columns 2 and 5 show the results of this equation for observations for which treatment was selected, while columns 3 and 6 show the results for disposal observations. Some parameters are shared by both types of observation (the coefficients on shipments, wages, energy prices, and industry dummies) but some differ because they compound the parameters from the price functions, $f_{\mathrm{T}}(\cdot)$ and $f_{\mathrm{D}}(\cdot)$, and the demand equation (2). Shared coefficients are shown centered between the two equations for which they are relevant.

The probit estimates in columns 1 and 4 of Table VI follow the same pattern as those in Table V, where the tax variables are in levels rather than logs. All coefficients have the expected signs and, with the exception of the tax rate on incineration in column 1, are statistically significant.

In the derived demand equations in columns 2 and 5, the point estimates for incineration taxes are similar to those estimated before. They are estimated much less precisely, however. In the first specification, the coefficient on incineration is negative, but not statistically significant. In the second specification, this coefficient is −11, in the middle of the previous range, and statistically different from zero at the 10% level. Thus, while the equations do not provide reliable elasticities themselves, they provide some additional support for the magnitudes of the elasticities suggested by earlier estimates.

[24] In defense of the assumption of independence in the errors, one might argue that waste characteristics (such as the concentration or extent of contamination) that are major sources of variation in treatment costs are not important determinants of disposal costs.

TABLE VI
Generation Decision with Selection of Management Method

	Management choice (probit) (1)	Generation amount Treatment (2)	Generation amount Disposal (3)	Management choice (probit) (4)	Generation amount Treatment (5)	Generation amount Disposal (6)
Log (tax on land disposal)	−0.507** (0.157)	—	1.87 (1.27)	−5.27** (1.20)	—	1.53 (1.89)
Log (tax on incineration)	3.32 (2.51)	−5.48 (3.76)	—	32.1** (6.4)	−11.0* (6.6)	—
Log (out-of-state disposal taxes)	—	—	—	−17.5** (4.3)	—	7.56 (6.77)
Log (out-of-state incineration taxes)	—	—	—	9.55** (1.97)	−3.39 (2.32)	—
Log (value of shipments)	—	0.055 (0.067)		—	0.054 (0.067)	
Log (wage)	—	−0.38 (0.25)		—	−0.34 (0.25)	
Log (industrial energy price)	—	0.17 (0.20)		—	0.06 (0.21)	
Selection term (disposal)	—	—	−6.39** (2.83)	—	—	0.44 (0.65)
Selection term (treatment)	—	3.38** (1.39)	—	—	2.53** (0.80)	—
R-squared		0.041			0.042	
N	3486	1719	276	3486	1719	276

Note. Standard errors in parentheses. Dummies for 2-digit SIC included in columns 2, 3, 5, and 6. Dummies for chemical and year included in all equations and allowed to vary by management method in columns 2, 3, 5, and 6.

The results for land disposal in columns 3 and 6 are disappointing. The point estimates of the coefficients are not statistically significant and fail to have the expected sign. The lack of success in estimating elasticities in these equations may result from small sample size (only 276 observations are used for these estimates). It is also possible that facilities that surprisingly report disposal in this period after the land disposal ban are less reliable than average in their reporting. The negative result may also arise from the failure of the model to capture fully variation in the cost of land disposal. For facilities using land disposal, liability considerations may play a larger role rather than direct costs.

5. IMPLICATIONS FOR WASTE GENERATION

The results suggest that waste generation is sensitive to variation in incineration costs. The elasticity of generation with respect to in-state incineration taxes appears to be quite high; point estimates range from −7 to −22. These high elasticities may be consistent with suggestions from the engineering literature that relatively simple process changes may reduce chlorinated solvent wastes, as discussed in Section 2.

The coefficient estimates in Table IV and may be compared with elasticities from a previous study by Wolf and Camm [22]. Wolf and Camm develop a model of demand for solvents that they parametrize with 1984 data and very rough estimates of the relevant elasticities. For the four chemicals studied here, they find generation elasticities from the price of incineration that range from −0.0026 for METH to −0.0079 for TCE. The generation elasticities for the price of land disposal are somewhat higher, ranging from −0.049 for METH to −0.15 for TCE. Thus, my estimates suggest a much larger role for price incentives in lowering the overall generation of solvent waste.

One should be cautious about interpreting the estimated coefficients as structural elasticities, however. The effect of the taxes on firms' actual waste management costs may be substantially lower than the tax rate for a few reasons. First, an increase in a state's tax rates will not raise all plants' costs equally. Plants that dispose waste out of state in the absence of a tax would not face any increased cost (if management services are provided perfectly elastically), while plants that begin disposing their wastes out-of-state as a result of the tax will face a somewhat lower increase in costs. Second, waste generators probably do not bear the entire tax, given the high costs of extending waste management capacity. In this case, the tax rates exaggerate the true variation in after-tax costs of waste management.

Table VII reports the implications of the parameter estimates for various waste-end tax programs. It shows both an optimistic view (high elasticities) and pessimistic view from the regressions in Tables IV and V about the effects of existing and proposed taxes. The predicted quantities under hypothetical policies are shown as a share of predicted generation and disposal with 1988 taxes.

Despite very high elasticity estimates, the table shows that the taxes in place in 1988 had only a small impact of waste generation. Without state taxes, waste generation would have been higher by 5 to 12%. This result arises because the taxes are only small share of total management costs. The proposed EPA taxes would have no impact on generation according to these estimates because they

TABLE VII

Implications of Waste-End Taxes for Waste Generation and Disposal in 1988

	Percent of 1988 quantities			
	Waste generation		Disposal	
	Pessimistic	Optimistic	Pessimistic	Optimistic
1988 taxes eliminated	105%	112%	111%	144%
EPA policy 2 land disposal: $19.96	100%	100%	95%	72%
EPA policy 3 land disposal: $45.37	100%	100%	86%	38%
CBO policy 2 land disposal: $16.29 incineration: $2.72	98%	95%	95%	82%

Note. Pessimistic predictions are based on elasticities column 1 in Table IV and column 1 in Table V. Optimistic predictions are based on column 4 in Table IV and column 4 in Table V. Changes are expressed as a share of predicted 1988 quantities. EPA and CBO policies (from Table II) rebate existing state taxes, so the tax is the maximum of these rates and the 1988 state tax rate.

only affect the cost of land disposal. The CBO proposal, which includes a small tax on treatment, would reduce generation by no more than 5%.

Table VII suggests that the waste-end taxes may have caused a greater proportional effect on disposal, but there is a great deal of uncertainty about magnitude of the effect. Without existing taxes, the amount of waste disposal might have been 11 to 44% higher. Much of this reduction is due to high taxes on disposal in California. Excluding California observations, the apparent reduction in disposal from the taxes is less than half as much; disposal would have been 19% higher (rather than 44% higher) assuming the optimistic parameters.

The empirical evidence for chlorinated solvents appears consistent with the engineering estimates presented in Table II for the effect of national waste-end taxes on all hazardous wastes. In particular, the EPA estimated that EPA policies 2 and 3 would both reduce landfilling of all kinds of wastes by about 60%. For the optimistic estimates, the reductions predicted by my analysis for chlorinated solvent waste disposal are 28 and 62%, respectively. Table VII may substantially underestimate the impact of a national tax, however. Because the option of shipping wastes out of state would not be available, both generation and management decisions might respond more dramatically to a national tax than to state taxes.

6. CONCLUSION

This study provides some evidence that taxes on emissions can alter the behavior of polluters if the taxes are imposed at a sufficiently high level. The econometric analysis suggests that facilities may respond quite elastically to changes in the cost of incineration. However, it fails to find a similar effect for changes in the cost of land disposal, which is used by a small number of facilities in the sample. Further, despite the apparent sensitivity of generation to incineration costs, current taxes are estimated to have only a very limited effect on total generation because they represent only a small share of total waste management costs.

States' experience thus suggests that taxes may provide an alternative to the standard-based policies now used for most hazardous waste regulation. However, these taxes are not an ideal policy instrument for several reasons. First, waste-end taxes may encourage illegal waste disposal [8, 19]. Because illegal dumping can be much more damaging to the environment than legal waste management, a small increase in this activity may have important consequences for the desirability of policy intervention. In the presence of illegal disposal, a deposit/refund program may be substantially less costly than a waste-end tax.

Second, waste-end taxes provide only an approximate means of differentiating among the environmental costs of various waste management methods. The environmental costs of disposing a certain quantity of waste will vary not just among broad classes of waste management methods, but within these classes as well.[25] A tax system directed at environmental releases (for example, air emissions from incineration, ground water contamination from landfills) could more accurately signal environmental costs to generators and waste management facilities.

[25] For example, Watabe [21] focuses on a situation in which the environmental cost varies not only with the amount of waste but also with the precautions taken to avoid accidents.

For example, the tax system should reflect geographical variations in the costs of pollutant releases which vary with factors such as hydrology and population density.

Finally, it is not clearly desirable to add waste-end taxes to the current hazardous regulatory program. Current RCRA regulations impose high waste management costs on many facilities. These policies may provide sufficient incentives for reduction of hazardous waste. More analysis would be required to assess the efficiency of further increasing these costs.

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