Environmental Policy and the Reduction of Hazardous Waste

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Abstract

Environmental policy encouraging hazardous waste reduction began in 1976 with an Environmental Protection Agency statement promoting source reduction as the preferred method of hazardous waste management. In 1984, Congress included a policy statement supporting waste reduction in the Hazardous and Solid Waste Amendments (HSWA). However, the cornerstone of HSWA was the land disposal restrictions (LDRs)—a command and control policy prohibiting land disposal of untreated hazardous waste. Consideration of the hazardous waste generation decision in the aggregate would suggest that the price effect resulting from the LDR program and increased hazardous waste management prices in general would lead to source reduction. Although at the firm level there may be interdicting factors, statistical analysis of generation data for Tennessee support this hypothesis. Both the institution of the LDRs and waste management prices have significant negative effects on the level of generation. The analysis, however, reveals the existence of large industry and firm effects, indicating that the response to public policy may exhibit significant variance, especially at the individual generator level.

INTRODUCTION

The first federal hazardous waste legislation was the Resource Conservation and Recovery Act (RCRA) of 1976. The RCRA established a cradle-to-grave national regulatory system to guard against inconsistent and ineffective state programs and market failures [Bowman, 1985; Florini, 1982]. It had four requirements for the U.S. Environmental Protection Agency (EPA): (a) identify hazardous wastes; (b) develop standards for generators and transporters and treatment, storage, and disposal facilities; (c) create a permitting process; and (d) establish a manifest system for tracking hazardous waste from generation to disposal. Also in 1976, the EPA issued a policy statement promoting waste reduction as the preferred management method for hazardous waste [U.S. EPA, 1976].

Journal of Policy Analysis and Management, Vol. 16, No. 4, 556–574 (1997)

Published by John Wiley & Sons, Inc. CCC 0276-8739/97/040556-19

The RCRA was amended in 1984 by the Hazardous and Solid Waste Amendments (HSWA). Key provisions of HSWA include the prohibition on land disposal of untreated hazardous waste, national regulation of small quantity generators, and minimum technology requirements for treatment and disposal facilities. Congress also declared in HSWA a national policy that when possible hazardous waste generation should be reduced or eliminated.

In RCRA and HSWA, the primary emphasis is unequivocally on developing a national regulatory scheme for hazardous waste management, a mechanism to protect human health and the environment through proper management of waste *after* it is generated. With RCRA the attention was on developing national standards. The "regulatory centerpiece" of HSWA was phasing out direct land disposal of waste and encouraging use of less risky (but more expensive) waste management options [Mazmanian and Morell, 1992, p. 102]. Congress did include a provision in HSWA that generators with off-site shipments certify a program is in place to reduce waste where economically practical. However, this "is an easy enough thing to certify," but may be a much harder provision for generators to implement [Herz, 1991, p. 1261]. Instead, actual waste reduction requirements were "minimal" (p. 1261).

This article focuses on the *outcome* of federal environmental regulation of hazardous waste, in particular, its effect on waste generation and reduction. We concentrate on federal regulation because of its efforts to develop national standards to eliminate weaker and seemingly ineffective regulatory programs that had evolved at the state level, particularly prior to 1976.[1] Moreover, we center on RCRA and HSWA as the two major federal legislative packages implemented for hazardous waste management [see Vig and Kraft, 1994]. We start with a brief review of the major aspects of evaluating public policy outcomes and outputs and then move to a specific environmental policy: hazardous waste reduction.

We employ a two-tierred effort to gauge the outcome of federal hazardous waste policy. First, we present hazardous waste decisionmaking from a system perspective at the aggregate level. Second, we are interested in identifying determinants of reduction in hazardous waste generation. We accomplish this through a waste generation model, building upon the system framework presented. With the waste generation model, however, we proceed from an aggregate policy perspective of the problem to firm-level analysis where actual waste reduction decisions are made and there are measurable, tangible results. Particular emphasis is placed on the land disposal restrictions (LDRs) included in HSWA. The LDR regulatory program was the fundamental component of HSWA, not waste reduction directly. Congressional intent was to allow economic incentives to encourage waste reduction [Mazmanian and Morell, 1992].[2] In essence, Congress attempted an indirect economic approach in HSWA by eliminating the least expensive waste management option. Thus, legislative actions, specifically the LDRs in HSWA and the increased waste management costs stemming from them, present a profit-seeking firm with choices between waste abatement/reduction actions or "business-as-usual" practices.

[1] Not all state regulatory programs should be viewed as ineffective [Lester, 1995]. Indeed, many state programs served as precedents for national programs [see Deyle and Bretschneider, 1995].

[2] We readily admit that state hazardous waste policies and federal policy on other waste management areas may influence firms' waste reduction behavior. However, we focus solely on the federal

The evaluation question addressed here then is: Has hazardous waste reduction occurred? If so, what were the underlying factors affecting the reduction; that is, did the congressional intent of economic incentives occur? Answers to the latter question are critical because Congress and states presume that economic incentives may sufficiently motivate waste reduction.

CHALLENGES IN EVALUATING OUTCOMES

Policy analysis allows researchers and decisionmakers to evaluate the outputs and outcomes of a government policy in an unbiased, systematic way. Outputs and outcomes are important because they can be quantified, evaluated empirically, and "represent the end result of a particular policy," as Waterman and Wood noted [1993, p. 685]. The evaluation of outputs and outcomes also provides empirical information on hypothetical assumptions developed when legislation is passed. Frequently the consequences of legislation may be different than the presumptions made when passed. The challenge of evaluation is recognizing and accounting for both the intended and unintended—or secondary—consequences of government policies and programs. Measurement of success or failure becomes increasingly germane when the objectives of government policies and regulations—particularly environmental command and control regulations—are scrutinized from this perspective.

In this case, evaluating the specific effects of the LDR program on waste reduction can determine whether congressional intent that economic factors would encourage waste reduction in fact occurred. Congress mandated that hazardous waste generators move away from a traditional land disposal regime. Generators would be forced to look "upstream" at management options perceived to be less risky (like incineration) but more expensive than land disposal. As generators evaluate more expensive "end-of-pipe" management options, they may investigate source reduction as a viable alternative. Congress and the EPA have yet to mandate specific waste reduction measures; rather, both have taken a voluntary approach. An evaluation of the economic consequences of the LDR program can assist in determining whether that is an acceptable policy.[3]

Much has been written on the implementation and adoption of environmental policies (outputs). Ironically, however, little empirical research has focused on the *outcomes* of these environmental policies. Ringquist [1995] and Freeman [1982] have investigated air and water quality. Regarding outcomes of hazardous waste policy, Deyle and Bretschneider [1995] examined spillover effects of state policy that preceded federal hazardous waste legislation. Specifically, they examined New York's land disposal restrictions (passed prior to the federal LDR program) and its tax linked to management technology on in-state generated as well as imported hazardous waste. They concluded that an increase in the state tax appears "to have discouraged imports to in-state landfills," and that the land disposal restrictions increased "waste shipments to other states" and a shift to other management technologies (p. 103). Their study is thorough

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LDR program as a major hazardous waste regulatory change with an underlying economic principle.

[3] There is some evidence to support the assertion that the LDR program proved instrumental in waste reduction [see Barkenbus and Barkenbus, 1989].

in its analysis of a state policy that preceded federal legislation and the effects beyond New York. It did not, however, focus on waste reduction *per se*, although they acknowledge that there is indirect evidence that state policies prompted waste reduction. Deyle and Bretschneider [1995] focused on innovative and progressive state policy. However, not all states were at the forefront of environmental policy; hence, the need for federal legislation. This article concentrates on an outcome of one set of federal regulatory policies: those pertaining to hazardous waste generation and management and the consequence for reduction efforts.

HAZARDOUS WASTE REDUCTION POLICY

In addition to promoting waste reduction in HSWA, Congress explicitly addresses waste reduction in the Pollution Prevention Act of 1990 by clearly expressing its encouragement of and support for waste reduction. The EPA has created an Office of Pollution Prevention, and several EPA-lead voluntary reduction programs are in place.

States have also been active in calling for hazardous waste reduction [Style, 1993–1994; Sullivan and Floyd, 1991]. At the federal and state levels, however, there have not been mandatory waste reduction requirements. Generators are left to devise schemes that reduce waste generation; this nonintrusive tone is clear in the federal Pollution Prevention Act as well as state legislation.

With emphasis on hazardous waste reduction as a voluntary public policy, it is particularly important to analyze the outcomes. It is also crucial to evaluate a reduction in hazardous waste generation through a deliberate process, not merely comparing generation numbers with little consideration of intervening factors. The crux of an evaluation process of pollution prevention is to examine factors that motivate a firm's decisionmaking process.

In this assessment of environmental quality, we have selected to measure hazardous waste generation in Tennessee for 15 standard industrial classification (SIC) codes. The measurement unit is hazardous waste generation at the firm level as reported to the Tennessee Department of Environment and Conservation (TDEC). There are 208 firms analyzed for the years 1985, 1987, 1989, and 1991. Hazardous waste generation is influenced by many variables including, but by no means limited to, economic activity, price of inputs, price of waste management services, regulatory oversight, and concerns about future liability. Generation does not occur in a vacuum; rather, firms are components of an interdependent, dynamic system. Moreover, it can be safely assumed that generators are generally concerned about their competitiveness and profitability.

We acknowledge that reduction of hazardous waste may not directly lead to improved environmental quality. Concern has been raised about the possibility of reducing volumes of waste but not toxicity. In addition, some analysts have argued that current policy on allowing indirect economic factors to serve as an impetus to waste reduction (as opposed to mandatory waste reduction) is little more than "greenwashing" [Gottlieb, Smith, and Roque, 1995, p. 198]. Nevertheless, it is useful to evaluate changes in hazardous waste generation as one measure of environmental quality. Waterman and Wood [1993] succinctly stress the importance of quantification: Hazardous waste generation can be quantified and empirically evaluated. Moreover, hazardous waste generation

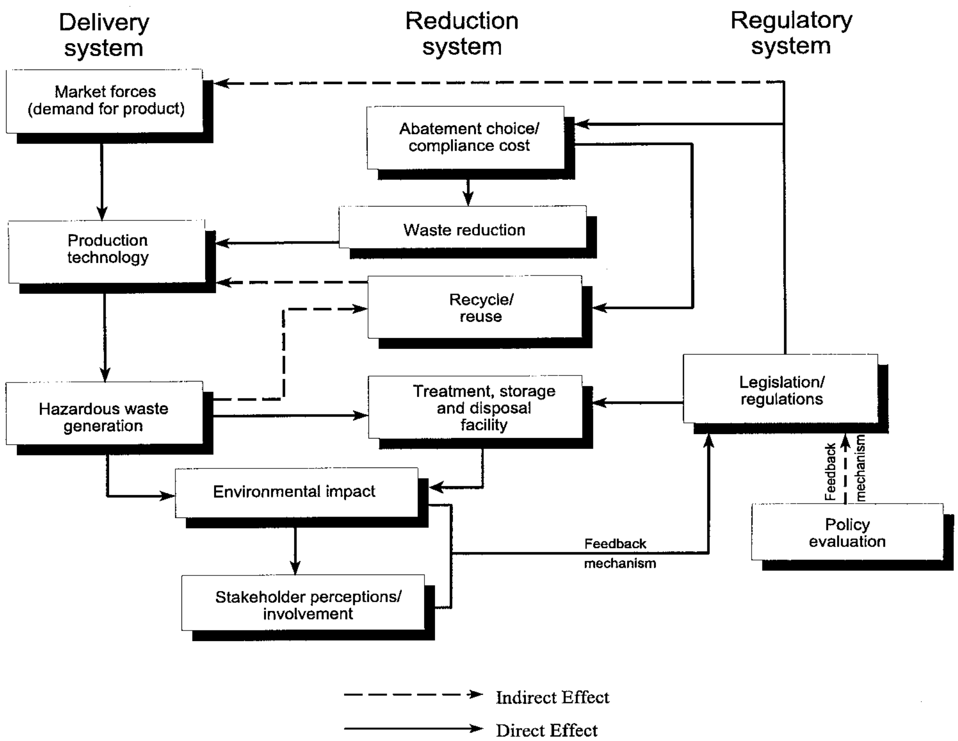

Figure 1. Conceptual framework of hazardous waste system. Dotted arrows: indirect effect; solid arrows: direct effect.

data have been identified as an environmental measurement indicator [see National Academy of Public Administration, 1995; Bergquist, Bernard, and Pable, 1995].

CONCEPTUAL FRAMEWORK FOR HAZARDOUS WASTE EVALUATION

A general framework for evaluation of hazardous waste regulation and public policy is presented in Figure 1. This policy analysis system involves interaction among three subsystems (the damage delivery system, the damage reduction system, and the regulatory system), and represents the entire waste-generating sector.

Delivery System

The damage delivery system depicts the simplified decisionmaking process of a typical hazardous waste-generating firm, but also presents a standard case of market failure resulting from the existence of an environmental externality. Recurrent hazardous waste generation is a direct result of the production of goods. Prior to any regulatory intervention, a firm, in response to demand for a product and given a set of relative prices for inputs and outputs, will choose a production technology and supply the product to the market with the least-cost waste management alternative chosen. A viable alternative, of course, is no management at all. With the environment underpriced from lack of direct or indirect regulation of the choice of waste management technology, the producer will not be concerned greatly with the disposal of waste unless there is potential for inexpensive reuse or a recycle market. Waste production will be maximized as production cost is minimized; that is, in the unregulated state, waste is disposed in the environment relatively "free of charge."

As a result, the product price is below marginal social cost and the users of the product do not pay the full cost of its production. Rather, these costs are distributed throughout the population and through time in the form of environmental degradation. The untreated waste is the direct cause of environmental impact or damage and the negative external costs borne by society [Barnett, 1994; Bohm, Moore, and Schmidt-Bleek, 1975]. Public perception of these costs may be negligible when the total amounts of waste produced are small. However, when the quantities increase and the environmental impact and ensuing costs become more obvious, public awareness of the danger generally will increase (witness the Superfund program) [see Barnett, 1994]. Environmental impacts—both monetary and nonmonetary—create the pressure for political action in the form of corrective laws and regulations. These stakeholder perceptions of a problem, together with possible equity concerns, lead to regulatory intervention.

Regulatory System

As previously discussed, two federal laws govern the recurrent generation of hazardous waste: the Resource Conservation and Recovery Act (RCRA) of 1976 and its 1984 amendments, the Hazardous and Solid Waste Amendments (HSWA). Generators who had previously generated waste with minimal interference, regulatory oversight, or concern with cost of waste management services were brought into a regulatory scheme. As shown in Figure 1, the development of corrective legislation and regulations is the most likely point of impact for successful policy analysis.

Reduction System

Linking the delivery and regulatory systems is the damage reduction system. Here, legislation and regulations define abatement choices, introduce compliance costs, and in this case created regulated treatment, storage, and disposal facilities (TSDFs). With respect to costs, there is the cost borne by a generator from being regulated: bringing a generator into a full-scale regulatory system increases manufacturing or production costs [see Bowman and Davis, 1989]. In addition, there is the cost of the required treatment and disposal itself.

As indicated in Figure 1, hazardous waste generators are now faced with a choice. On the one hand, they could engage in waste reduction and alter their production technology. Alternatively, if treatment and disposal costs are low, the waste generated from relatively unchanged production processes will either be recycled or reused, or more commonly be set to a TSDF. In many instances, prior to HSWA, hazardous waste was sent to land disposal units.

This could be the end of the story if there is significant reduction in damage and if the compliance cost is modest. On the other hand, if the abatement system is inadequate or there is still a perception of danger, a demand for more stringent public policy will be generated. In the chronology of hazardous waste regulation, this is the point at which HSWA is introduced into the regulatory system.

The pre-HSWA system is a clear example of an end-of-pipe solution to an environmental problem, that is, the impetus for waste reduction was nil and action takes place after the agents causing damage are produced. In fact, because these end-of-pipe regulations permitted inexpensive and apparently ineffective land disposal, environmental impacts may not be much different than existed before RCRA. However, the situation changes radically with the introduction of the LDR provisions under HSWA.

Moving through the reduction system a second time, generators are now faced with increased waste management costs that are greater than the cost differential between land disposal and the next least expensive management option. Other things equal, the LDR program provides a powerful incentive to reduce waste directly or to recycle/reuse, when feasible. More technically, the relative price of waste reduction and recycle/reuse has fallen encouraging generators to consider upstream solutions to their hazardous waste problems.

A MODEL OF WASTE GENERATION AT THE FIRM LEVEL

At the aggregate level, the logic of the policy analysis framework presented in Figure 1 suggests that the effect of the LDRs will be to reduce hazardous waste generation. As discussed earlier, this result would be congruent with congressional intent. At the microlevel, however, the validity of this hypothesis rests on the reaction of generators to such changes in waste management policy *vis-a-vis* other factors that influence the firm's decisionmaking process. Whether the firm chooses to introduce new procedures, inputs, or production methods designed to reduce the amount of waste generated per unit of output will depend upon relative costs. If regulatory constraints or market conditions change so as to increase the final costs of end-of-pipe waste management, firms would likely weigh this effect against the costs of more waste reduction.

Indeed, firm behavior under these conditions can be specified as a general profit-maximization problem.[4] Assume a single representative firm, producing a single good, operates within a perfectly competitive market. With factor markets assumed to be competitive as well, both input prices and the price of output are exogenously determined. For simplicity, the production process generates a single stream of hazardous waste the firm must dispose of in compliance with existing regulations. The analysis is easily extended to vectors of goods, waste streams, and prices. A market for waste management services exists and also is assumed to be perfectly competitive. In addition, government regulations may affect waste management market conditions; consequently, the management price reflects a given state of regulation.

The representative firm chooses the level of output and waste reduction, or abatement, expenditures which maximize profits when the output price, state of regulation, and waste management price are given. Explicitly the firm's maximization problem can be specified as follows:

[4] The abbreviated derivation which follows in the text represents the application of standard economic theory to the problem at hand. See Varian [1992, especially chapters 2 and 27]. The comparative statics are included to demonstrate the theoretical foundations of the empirical work that follows and to establish the basis for interpreting results. The complete mathematical exercise will be provided to interested readers upon request.

$$MAX_{XA}: \Pi = pX - C(X, A) - qW(X, A) \tag{1}$$

where X is total output; A is waste abatement expenditures; Π is total profits; p is the price of output; C is a total cost function, dependent upon the level of output and abatement expenditures; q is the per unit waste management price; and W is the waste generation function, which is dependent upon the level of output and abatement expenditures.[5] Assuming an interior solution, the first-order conditions for a maximum are:

$$C_x = p - qW_x \tag{2}$$

$$C_A = -qW_A \tag{3}$$

where subscripts represent partial derivatives. Equation (3) shows that the firm will choose output and abatement such that marginal abatement costs are equal to the marginal benefits of waste reduction, that is, the negative of waste management price multiplied by the marginal product of abatement. From equations (2) and (3), the optimal levels of output, X^*, and abatement, A^*, can be determined. The general functional forms are shown as:

$$X^* = h(p, q) \quad A^* = g(p, q)$$

Substituting X^* and A^* into W in equation (1) gives the optimal generation of waste:

$$W^* = W^*(X^*, A^*) \tag{4}$$

In addition to the relationships W_X and W_A, expected to be positive and negative respectively, the effect of changes in the management price on waste generation is also of particular interest. Differentiating equation (4) with respect to q, the following expression is obtained, dropping the * superscripts for convenience:

$$W_q = (W_X)(X_q) + (W_A)(A_q) \tag{5}$$

Equation (5) will be unambiguously negative if X_q is nonpositive, and A_q is positive. By totally differentiating the first-order conditions, it can be shown that the required signs on the two previous terms will be realized if the following result holds:

$$C_{XA} + qW_{XA} \geq 0 \tag{6}$$

Intuitively marginal costs of producing output X should increase at higher levels of abatement expenditures, whereas waste generated per unit of output should fall as abatement increases.[6]

From our analysis, it is clear that there is some uncertainty as to the effect of higher waste management prices on waste generation. The outcome will depend upon the relative effects of abatement on marginal production costs

[5] The following relationships are assumed *a priori:*

$$C_X > 0, \quad C_{XX} > 0, \quad C_{XA} > 0, \quad C_A > 0, \quad C_{AA} > 0,$$
$$W_X > 0, \quad W_{XX} = 0, \quad W_{XA} < 0, \quad W_A < 0, \quad W_{AA} > 0,$$

with subscripts representing first and second partial derivatives.

[6] The first term in equation (6) is the rate of change in marginal production costs with respect to a change in abatement expenditures, whereas the second term expresses the value of the marginal rate of waste generation with respect to a change in abatement expenditures.

and marginal waste generation, for any given management price. However, whenever marginal waste management costs are higher than marginal abatement costs, including any additional marginal production costs, an increase in abatement efforts would be expected.

The net effect of the impact of the price of waste management services on hazardous waste generation can be viewed as an empirical question. Based on equation (4), an empirical model of firm-specific waste generation can be expressed in general form as follows:

$$W_{i,j,m,n,t} = f[P_{m,n,t}; Y_{i,j,t}; R_{m,t}; I_{j,t}; F_{j,t}; u_t] \tag{7}$$

where $W_{i,j,m,n,t}$ is the amount of waste generated by firm i, in industry j, of waste code m, subject to management method n, in year t, and where:

$P_{m,n,t}$ is the price of managing waste code m by method n in year t;
$Y_{ij,t}$ is the output (value added) of firm i in industry j in year t;
$R_{m,t}$ is the regulatory structure covering waste code m in year t;
I_{jt} is industry-specific factors for industry j in year t;
$F_{i,t}$ is firm-specific factors for firm i in year t; and
u_t is a stochastic disturbance term.

Note that the waste generation variable is specific with regard to waste code and waste management method as well as industry, firm, and time. The price effect is represented by both the regulatory variable and specific waste management prices. This specification allows regulatory changes to have impacts upon firm behavior even if there are no changes in current year waste management prices. Output effects, as well as industry- and firm-specific conditions, are controlled for by the remaining variables. The latter two variables serve as proxies for unobservable or confidential factors such as prices of different factor inputs, costs of various abatement strategies, and firm-specific production levels.

The variables of particular interest are waste management price P, the regulatory regime R, and output Y. The relationship between waste generation and output is expected to be positive, while the effects of both waste management price and regulatory incidence are expected to be negative. The expected signs of P and R reflect the hypothesis that the policy framework presented in Figure 1 is operational as described (that is, congressional intent is fulfilled) and that the inequality in (6) is as shown.

DATA SOURCES AND VARIABLE SPECIFICATION

A panel of hazardous waste-generating firms in Tennessee over the years 1985, 1987, 1989, and 1991 has been constructed to estimate the model. In equation (7), the dependent variable is written to reflect the richness of the data available from TDEC. The RCRA defines hazardous waste in generic (characteristic) terms (such as ignitable, corrosive, reactive, or toxic) and lists specific wastes and waste streams (for example, lead, wastewater treatment sludges from electroplating operations, and the like). These hazardous wastes are classified by an EPA waste code [see Code of Federal Regulations (CFR) §§ 261.21–24 (characteristic wastes) and §§ 261.30–34 (listed wastes)]. All Tennessee firms generating more than 100 kilograms of hazardous waste per month are man-

Table 1. Manufacturing standard industrial classification (SIC) codes.

SIC code	Description
20	Food and kindred products
22	Textile mill products
24	Lumber and wood products, except furniture
25	Furniture and fixtures
26	Paper and allied products
27	Printing, publishing, and allied industries
30	Rubber and miscellaneous plastics products
32	Stone, clay, glass, and concrete products
33	Primary metals industries
34	Fabricated metal products, except machinery and transportation equipment
35	Industrial and commercial machinery and computer equipment
36	Electronic and other electrical equipment and components, except computer equipment
37	Transportation equipment
38	Measuring, analyzing, and controlling instruments; photographic, medical, and optical goods; watches and clocks
39	Miscellaneous manufacturing industries

dated to file reports with the TDEC. Every generator must submit a hazardous waste stream report form for *each* waste stream generated in a calendar year.[7] The form requires a firm to report the EPA waste code (e.g., D008, F006), waste name (e.g., lead, electroplating sludge), hazard criteria (e.g., ignitable, corrosive), and physical form (e.g., percent solid, percent water), among other things. In addition, generators are required to include in the hazardous waste stream report form the on-site and off-site management of the waste (for example, incineration, solvents recovery, and neutralization). Any combination of on-site and off-site management is incorporated into the form for tracking management of the total volume generated.

The TDEC data derived from the hazardous waste stream report forms are the source of all generation data used in this study. It was reviewed for all firms with continuous operations and nontrivial generation; that is, generation of hazardous waste over the entire seven-year period, and generation of at least 10 tons of waste in the initial year of analysis, in 15 different SIC codes (see Table 1). Admittedly, restricting the first year's generation to more than 10 tons tends to limit the analysis to larger firms. The continuous generation requirement over the study period also is restrictive. A waste generation of zero could occur due to process change, material substitution, business closure, or failure to report. The first three are behavioral changes that could occur due to the imposition of the LDR. If included in our analysis, the results would no doubt be strengthened. On the other hand, if the reason for $W = 0$ is failure to report, we would claim waste reduction when none has occurred. Because it is not possible to determine the exact cause of $W = 0$, we chose continuous generation. The result is a sample of 208 firms.[8] For each year, the amount of

[7] The forms used by TDEC are extensive in their data gathering capability and exceed the minimum requirements set out in the EPA's biennial report forms.

[8] As can be observed in Table 1, SIC 28 (chemical products) is omitted. This is due to the domination of a single large firm in this industrial sector.

waste generated, waste code classification, and management can be observed for each firm. The following management methods are covered: solvents recovery, energy recovery, stabilization, incineration, wastewater treatment, wastewater sludge treatment, and direct landfill.[9]

A per-ton management price, for each of the four periods covered, is associated with each management method. These data reflect average market prices charged by TSDFs for managing waste, exclusive of transportation costs and host state-imposed fees. They are method (e.g., incineration) and year specific (e.g., 1985), but do not vary by waste code and have been obtained from several sources including ICF's national survey conducted for the EPA, Peretz and Solomon's survey, and various other surveys [ICF, 1992; Peretz and Solomon, 1995; Ed Martin, personal communication, 1994; Kathy Rees, personal communication, 1994; Brett Schofield, personal communication, 1994; Karen Talley, personal communication, 1994; Kathleen D. Ward, personal communication, 1994]. In those cases where waste management prices were collected from several sources (like several energy recovery facilities), mean values are used. Nominal prices per management method are entered into the data set as an index relative to the 1985 landfill price.

To be sure, the use of average market price data is not ideal, but is the best available alternative. Final waste management prices are derived through negotiation between the waste management firm and the hazardous waste generator and are considered confidential. This detail is lost in a set of average prices. However, average prices can be expected to capture the general trend in the cost of hazardous waste management services which is the essential characteristic of price of interest in this analysis. Even capturing this trend, however, cannot avoid the obvious mismeasurement of the price variable, a clear limitation to our analysis, and a factor that can be completely ignored only if assumptions regarding perfect competition hold in the extreme [Greene, 1993; Kennedy, 1994].

The regulatory structure analyzed is the incidence of the LDRs contained in HSWA [CFR, 1992]. The initial restriction on land disposal—the prohibition on placing noncontainerized or bulk liquid hazardous waste in any landfill—was effective in May 1985. After that, the LDR program was phased-in through five stages. Land disposal of spent solvents and dioxin-containing wastes was prohibited effective 24 months after HSWA's passage; land disposal of the so-called California-listed hazardous wastes was prohibited effective 32 months after passage. The HSWA required that all remaining hazardous wastes be divided into three groups based on their "intrinsic hazard and their volume" [HSWA, § 201(g)(2)]. These groups—commonly known as the first, second, and third "thirds"—were banned from land disposal 45, 55, and 66 months, respectively, after passage of HSWA. The variable R in equation (7) is specified as a discrete dummy variable that takes the value one for all years in which a waste code is covered by the LDRs, and is zero otherwise. This specification takes explicit account of the phase-in of LDRs in the years following the passage of HSWA.

Generally, firm-level output data are not available. Two proxies have been experimented with to represent the variable Y in equation (7). These are annual

[9] With the possible exception of stabilization, these terms are self-explanatory. In lay terms, stabilization refers to increasing the volume of a waste stream through the addition of a solidification element, such as cement.

nominal gross state product (GSP) originating by two-digit SIC industry and annual nominal total GSP. Both variables are available annually [Fox and Price, 1994]. Although a more disaggregated specification would appear preferable from a theoretical point of view, these aggregate forms appear to be satisfactory substitutes in capturing broad changes in the level of economic activity. Interestingly, total GSP performs slightly better than GSP originating by industry and is the specification reported in the results presented later.

The variable I is intended to take account of unspecified industry-specific factors which affect waste generation. A separate dummy variable is defined for each SIC industry. These 15 variables take the value one for all observations within that industry and are zero otherwise. The industry with the largest generation in the sample, SIC 34, is used as the reference industry for estimation purposes. Likewise, the variable F takes account of unspecified firm-specific factors. There is one variable for each firm in the data set. It takes the value one for observations on that firm's generation and is zero otherwise. The firm with the largest generation in the sample is omitted for estimation purposes.

EMPIRICAL MODEL SPECIFICATION

For estimation purposes, two aggregations of the data are considered. In one case, waste generation amounts are summed by waste code. In the second, they are summed by waste code and management method.[10] The first aggregation isolates waste codes while allowing variation in treatment methods across firms and over time. It specifically captures industry and firm responses to the elimination of direct landfill as a disposal option. Management price, as a determining factor, is attenuated. It is expected that regulation will show a stronger impact on waste generation than direct prices. In the second aggregation, waste generation is summed over management method as well as waste code. Because the method of management does not change over the entire time period, price effects are highlighted over changes in treatment options. Regulation enters as an indirect factor, but is still expected to be significant.

An additional "aggregation" issue must be considered. The variables I and F cannot be other than highly collinear. The firm-based variable is the more comprehensive of the two, as it would seem inconceivable to eliminate industry factors from the firm's decisionmaking matrix. Thus, an empirical model which includes only the variable F would capture both industry and firm effects, albeit jointly. The existence of industry-only effects can be tested somewhat by summing over firms to the industry level, that is, by including only the variable I. If industry effects are important, a model including I would have improved explanatory power over a model without I or F. The existence of independent firm-level effects (in addition to industry-level effects) would seem a plausible conclusion if the explanatory power of a model with the variable F only exceeded that of a model with the variable I only.

[10] These aggregations have both a theoretical and a practical basis. Theoretically, the model defined by equations (1) through (6) focuses on the total waste management decision of the firm. Additional factors would have to be considered in order to extend the model to the individual waste code level. On the practical level, most individual waste codes would violate the annual amount constraint of 10 tons per year. The determinants of individual waste code management decisions are not unimportant, however, and will be the subject of future analysis by the authors.

Four empirical models are available for estimation based on these aggregations. An "industry" model ($I = 1 \ldots q$):

$$W_{1,2} = \alpha + \beta_1 Y_t + \beta_2 P_{n,t} + \beta_3 R_{m,t} + \beta_4 I_{1,t} + \cdots + \beta_K I_{q,t} \tag{8}$$

where W_1 represents $W_{j,m,t}$ for the aggregation over waste codes (Industry Model 1), and W_2 represents $W_{j,m,n,t}$ for the aggregation over waste codes and management method (Industry Model 2); and a "firm" model ($F = 1 \ldots z$):

$$W_{1,2} = \alpha + \beta_1 Y_t + \beta_2 P_{n,t} + \beta_3 R_{m,t} + \beta_4 F_{1,t} + \cdots + \beta_K F_{z,t} + u_t \tag{9}$$

where W_1 represents $W_{i,m,t}$ for the aggregation over waste codes (Firm Model 1), and W_2 represents $W_{i,m,n,t}$ for the aggregation over waste codes and management method (Firm Model 2). In all cases the restriction of nontrivial continuous generation has been imposed. The two industry models capture 98.6 percent and 93.7 percent of total generation, respectively, whereas the two firm models capture 87.2 percent and 82 percent of total generation, respectively.

EMPIRICAL RESULTS

The two empirical models set out in equations (8) and (9) are examples of the fixed-effects model used frequently in panel data analysis.[11] Initial OLS estimates of equations (8) and (9) in linear form were examined for nonspherical disturbances and multicollinearity, and a problem with heteroskedasticity was discovered. This was corrected by transforming the dependent variable W to $\ln W$ and reestimating equations (8) and (9) with OLS in semilog form.[12] Regression results are presented in Table 2 (Industry Model) and Table 3 (Firm Model). In both cases, estimates are shown with and without the fixed-effects variables.

In general, results are quite robust. Table 2 shows that the variables R, P, and Y all have the expected sign and are statistically significant at normally acceptable levels. The magnitudes of the coefficients for these variables do not change dramatically with the inclusion of industry fixed effects. Nine of the industry dummy variables are statistically significant in both Industry Model 1 and Industry Model 2. The coefficient for SIC 35 is significant in Industry Model 1 only. All of the significant fixed effects are negative with respect to SIC 34, the reference industry, that is, the regression plane for SIC 24, SIC 25, and the like is below that of SIC 34. However, this is not a surprising result given the fact that SIC 34 is the largest hazardous waste generating sector in the sample.

In comparison to the industry model, results from estimating the firm model are not as consistent. As shown in Table 3, the price variable is not statistically significant in Firm Model 2, although it is of the correct sign, whereas Y is significant only once and has the incorrect sign in Firm Model 2 in the fixed-

[11] The fixed-effects model is the appropriate choice in this case as the sample of firms would be the same in repeated draws. All observations that meet the restriction of nontrivial continuous generation are retained [see Baltagi, 1995, especially chapters 2 and 3].

[12] Two standard options are available for dealing with heteroskedasticity: weighted regression and altering the functional form. The latter approach has been chosen because no set of appropriate weights could be justified on theoretical grounds. In addition, data limitations hindered an ad hoc approach [see Greene, 1993, especially chapter 14].

Table 2. Estimates of fixed-effects industry model.

	Without fixed effects		With fixed effects	
Variable	Model 1	Model 2	Model 1	Model 2
Intercept	3.199***	3.525***	4.749***	5.230***
	(1.124)	(1.300)	(1.027)	(1.199)
R	−1.318***	−1.463***	−1.075***	−1.341***
	(0.361)	(0.417)	(0.319)	(0.374)
P	−0.008***	−0.010***	−0.006***	−0.014***
	(0.002)	(0.003)	(0.002)	(0.003)
Y	0.042**	0.036**	0.033**	0.039**
	(0.015)	(0.017)	(0.013)	(0.015)
SIC 20	—	—	1.508	1.376
			(1.041)	(1.210)
SIC 22	—	—	−0.130	−0.045
			(1.043)	(1.207)
SIC 24	—	—	−3.042***	−3.360***
			(0.065)	(0.765)
SIC 25	—	—	−2.378***	−2.518***
			(0.504)	(0.638)
SIC 26	—	—	−1.166**	−2.378***
			(0.583)	(0.637)
SIC 27	—	—	−0.944*	−1.403**
			(0.481)	(0.577)
SIC 30	—	—	−1.733***	−2.812***
			(0.540)	(0.631)
SIC 32	—	—	−3.717***	−4.560***
			(0.539)	(0.894)
SIC 33	—	—	0.391	0.326
			(0.446)	(0.576)
SIC 35	—	—	−1.809**	0.667
			(0.649)	(1.265)
SIC 36	—	—	−1.539***	−2.472***
			(0.504)	(0.577)
SIC 37	—	—	0.215	−0.697
			(0.434)	(0.509)
SIC 38	—	—	−0.848	−0.722
			(0.650)	(0.894)
SIC 39	—	—	−2.107***	−2.888***
			(0.537)	(0.688)
R^2	0.081	0.078	0.313	0.279
df	316	280	302	266

Notes: Standard errors are presented below estimated coefficients. Model 1 aggregates across waste codes only. Model 2 aggregates across waste codes and management methods.

* Significant at the 0.10 level of confidence.

** Significant at the 0.05 level of confidence.

*** Significant at the 0.01 level of confidence.

effects form. Still, the results presented in Table 3 are encouraging, particularly with respect to the regulatory variable which is consistently negative and statistically significant. Although the coefficients of the firm fixed-effects variables are not shown to conserve space, the individual firm coefficients that are statistically significant at the 0.10 percent level or better range in value from

Table 3. Estimates of fixed-effects firm model.[a]

	Without fixed effects		With fixed effects	
Variable	Model 1	Model 2	Model 1	Model 2
Intercept	3.572***	3.437***	10.516***	11.203***
	(0.825)	(1.292)	(1.064)	(1.086)
R	−1.153***	−1.807***	−0.698***	−0.643**
	(0.264)	(0.412)	(0.231)	(0.290)
P	−0.003***	−0.006	−0.002***	−0.003
	(0.001)	(0.005)	(0.001)	(0.005)
Y	0.017	0.030	0.004	−0.004*
	(0.011)	(0.017)	(0.010)	(0.011)
R^2	0.055	0.079	0.508	0.724
df	564	292	456	184

Notes: Standard errors are presented below estimated coefficients. Model 1 aggregates across waste codes only. Model 2 aggregates across waste codes and management methods.

[a] Coefficient estimates for individual firm dummy variables are available from the authors.

* Significant at the 0.10 level of confidence.

** Significant at the 0.05 level of confidence.

*** Significant at the 0.01 level of confidence.

−2.116 to −9.566 in Firm Model 1 (relative to an intercept of 10.515) and from −1.882 to −9.177 in Firm Model 2 (relative to an intercept of 11.203). All coefficients are negative in both firm models. In Firm Model 1 only 3 of 138 coefficients are not statistically significant at the 0.10 level or better, whereas the comparable result for Firm Model 2 is 4 of 70.

There would appear to be both industry and firm fixed effects influencing hazardous waste generation. A comparison of the adjusted R^2 across estimates shows a considerable increase with the inclusion of the fixed-effects variables. In particular, the sequence of the increase from estimates without fixed effects (lowest) to estimates with industry fixed effects and then estimates with firm fixed effects (highest) supports the hypothesis of independent firm-level influences that affect the amount of hazardous waste generated. The magnitude and level of statistical significance of the vast majority of the firm variables in the firm model would appear to support this hypothesis also.

If the decision by a firm to generate more or less hazardous waste is greatly determined by unique industry and firm conditions, is there a role for public policy? Certainly the result that generation is positively related to GSP supports the hypothesis, all other things being equal, of more output, more waste. However, the variables of greatest policy potential are the price variable and, in particular, the regulation variable. Table 4 presents results which highlight the impact of these variables on hazardous waste generation based on the four fixed-effects estimates presented in Tables 2 and 3. These results are evaluated at the means of the continuous variables for the reference case of each model listed in column one of the table. Column 2 shows the average percentage decrease in hazardous waste generation by a firm as its waste becomes covered by the LDRs.[13] These percentages range from 47.4 percent (Firm Model 2) to

[13] The percentage decrease in the variable W cannot be computed directly from the estimates presented in Tables 2 and 3 as the expected value $E(\ln W)$ is less than $\ln E(W)$ by Jensen's inequality

Table 4. Impact of land disposal restrictions (LDRs) and management price on generation of hazardous waste.[a]

Model	Reduction due to LDRs (%)	Price elasticity
Industry Model 1	65.8	−0.888
Industry Model 2	73.8	−1.728
Firm Model 1	50.2	−0.369
Firm Model 2	47.4	[b]

[a] Evaluated at the means for reference case.
[b] Estimated coefficient not significantly different from zero.

73.8 percent (Industry Model 2). Reductions such as these, based on highly significant coefficients of a carefully specified LDR variable, are nothing short of spectacular and attest to the apparent power of this form of regulation. The management price elasticity is derived from the coefficient of the variable P and presented in Table 4, column 3 [Goldberger, 1964]. The price variable is statistically significant in three of the four cases and the elasticity ranges from just below unity to −1.728 in the industry models, to −0.369 in the case of Firm Model 1. Particularly in the case of the firm model, it would appear that the price variable takes something of a back seat in comparison to the regulatory variable. Both the weakness of the price variable in the firm model and the difference in the magnitude of the coefficients in the firm model versus the industry model can, in part, be attributed to measurement error as noted earlier. On the other hand, the regulation variable undoubtedly captures most of the price effect in the model, as available management alternatives after the LDRs take effect imply a large shift in management prices facing generators. The remaining variance in generation to be explained by price is merely the relative price effects of the available management technologies over time. Even after accounting for the severe price shock reflected by R, these relative price effects retain importance in determining waste management behavior.

CONCLUSIONS

Many environmental policy researchers have lamented the difficulties in assessing the effects or outcomes of environmental regulations [Bartlett, 1994; Rosenbaum, 1995, p. 75]. Although we generally agree, we suggest that policy analysis affords the opportunity to evaluate whether the expectations of legislative action and public policy in fact lead to results envisioned by policymakers. In particular, our analysis indicates that HSWA's emphasis on deterring the use of land disposal for untreated hazardous waste also leads to waste reduction because of an increase in waste management costs faced by hazardous waste generators. Thus, the legislative intent implicit in our hazardous waste evaluation system is fulfilled, namely, that the LDR program creates economic incentives sufficient to alter waste generation behavior.

Specifically, the results of our statistical analysis show that the LDR regulations have a sizable negative impact on hazardous waste generation in Tennes-

[White, 1984, p. 27]. The correction given by Pankratz [1983, pp. 256–257] is used. On lognormal distributions in general see also Evans, Hastings, and Peacock [1993, especially pp. 102–105].

see. The signs of the coefficients in the empirical analysis support *a priori* expectations and are consistent with our theoretical analysis. Although it cannot be said with certainty that equation (6) holds, the implication is that, for this set of industries over this time period, it does. In addition to the effect of the LDRs, waste management price can be a significant factor in reducing the amount of hazardous waste generated while output growth, all other things being equal, leads to more.

On the other hand, it would appear that the waste reduction decision is highly firm specific, which has implications for future waste reduction evaluation programs undertaken at the state and federal level. To date, voluntary participation studies have focused on industrial sectors or on parent companies [see, for example, Arora and Cason, 1995, p. 278; Press and Mazmanian, 1977]. Our findings suggest that there are both industry- and firm-specific factors at work. Each firm has its own unique set of circumstances, even across industrial and parent (that is, non-Tennessee) companies.

The two clear results of this study—the waste reduction effect of the LDRs and the importance of firm-specific effects—are seminal in the realm of measuring the impact of an environmental public policy. In addition, the effects are transmitted by the market albeit originating with the strongest of command and control regulations, namely, a ban. In an era where the abandonment of command and control approaches is often advocated in favor of market mechanisms, such as environmental taxes and permit schemes, it is a prudent lesson to learn that at least one regulation has an important economic dimension that operates through the market as well.

Future research should focus on whether the economic influence imbedded in the LDR program continues to hold; the emissions versus toxicity question; and an extended time-series analysis. This study, however, has clearly illustrated the connection among regulation, reduction, and generation. Ignoring the interrelationships of this complex system and failing to properly measure them will lead to the ineffective environmental policy evaluation many analysts have feared.

We acknowledge the assistance of Marta Edwards, Peter Bearse, Amy Farmer, Jeffrey Louallen, Patrice Burley, and Kelly Rose. The reviewers' thoughtful comments are greatly appreciated. Financial support for this work was received from the Tennessee Department of Environment and Conservation and the University of Tennessee's Waste Management Research and Education Institute. The authors remain responsible for all errors and opinions.

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REFERENCES

Arora, Seema and Timothy N. Cason (1995), "An Experiment in Voluntary Environmental Regulation: Participation in EPA's 33/50 Program," *Journal of Environmental Economics and Management* 28, pp. 271–286.

Baltagi, Badi H. (1995), *Econometric Analysis of Panel Data* (New York: John Wiley).

Barkenbus, Jack N. and Barkenbus, Belgin D. (1989), "Industrial Response to a Waste Minimization Survey in Tennessee," *Air and Waste* 39, pp. 921–926.

Barnett, Harold C. (1994), *Toxic Debts and the Superfund Dilemma* (Chapel Hill, NC: The University of North Carolina Press).

Bartlett, Robert V. (1994), "Evaluating Environmental Policy Success and Failure," in Norman J. Vig and Michael E. Kraft (eds.), *Environmental Policy in the 1990s: Toward a New Agenda,* 2nd ed. (Washington, DC: Congressional Quarterly).

Bergquist, Gilbert T., James R. Bernard, and Andrea M. Pable (1995), *Prospective Indicators for State Use in Performance Agreements,* report prepared under State Environmental Goals and Indicators Project (Tallahassee, FL: Florida Center for Public Management, Florida State University).

Bohm, Robert A., John R. Moore, and Fredrich Schmidt-Bleek (1975), "Benefits and Costs of Surface Mine Reclamation in Appalachia," in M. Granger Morgan (ed.), *Energy and Man: Technological and Social Aspects of Energy* (New York: IEEE Press).

Bowman, Ann OM. (1985), "Hazardous Waste Management: An Emerging Policy Area within an Emerging Federalism," *Publius: The Journal of Federalism* 15, pp. 131–144.

Bowman, James S. and Charles Davis (1989), "Industry and the Environment: Chief Executive Officer Attitudes, 1976 and 1986," *Environmental Management* 13(2), pp. 243–249.

Code of Federal Regulations [CFR] (1992) 40, parts 260 to 299, pp. 850–859.

Deyle, Robert E. and Stuart I. Bretschneider (1995), "Spillovers of State Policy Innovations: New York's Hazardous Waste Regulatory Initiatives," *Journal of Policy Analysis and Management* 14(1), pp. 79–106.

Evans, Merran, Nicholas Hastings, and Brian Peacock (1993), *Statistical Distributions* (New York: John Wiley).

Florini, Karen L. (1982), "Issues of Federalism in Hazardous Waste Control: Cooperation or Confusion?" *Harvard Environmental Law Review* 6, pp. 307–337.

Fox, William F. and Patricia A. Price (1994), *An Economic Report to the Governor of the State of Tennessee* (Nashville, TN: The Tennessee State Planning Office).

Freeman, A. Myrick (1982), *Air and Water Pollution Control: A Benefit Cost Assessment* (New York: John Wiley).

Goldberger, Arthur S. (1964), *Econometric Theory* (New York: John Wiley).

Gottlieb, Robert, Maureen Smith, and Julie Roque (1995), "Greening or Greenwashing? The Evolution of Industry Decisionmaking," in Robert Gottlieb (ed.), *Reducing Toxics: A New Approach to Policy and Industrial Decisionmaking* (Washington, DC: Island Press).

Greene, William H. (1993), *Econometric Analysis,* 2nd ed. (Englewood Cliffs, NJ: Prentice-Hall).

Hazardous and Solid Waste Amendments (HSWA) of 1984, Public Law 98–616, 98th Cong., 2nd session, November 8, 1984.

Herz, Michael (1991), "Environmental Auditing and Environmental Management: The Implicit and Explicit Federal Regulatory Mandate," *Cardozo Law Review* 12, pp. 1241–1263.

ICF, Inc. (1992), *1990 Survey of Selected Firms in the Hazardous Waste Management Industry* (Fairfax, VA: ICF).

Kennedy, Peter (1994), *A Guide to Econometrics* (Cambridge, MA: MIT Press).

Lester, James P. (1995), "Federalism and State Environmental Policy," in James P. Lester (ed.), *Environmental Politics and Policy: Theories and Evidence,* 2nd ed. (Durham, NC: Duke University Press).

Mazmanian, Daniel A. and David Morell (1992), *Beyond Superfailure: America's Toxics Policy for the 1990s* (Boulder, CO: Westview Press).

National Academy of Public Administration (1995), *Setting Priorities, Getting Results: A New Direction for EPA* (Washington, DC: National Academy of Public Administration).

Pankratz, Alan (1983), *Forecasting with Univariate Box–Jenkins Models: Concepts and Cases* (New York: John Wiley).

Peretz, Jean H. and Jeffrey Solomon (1995), "Hazwaste Landfill Costs on Decline, Survey Says," *Environmental Solutions* 8(4), pp. 21–25.

Press, Daniel and Daniel A. Mazmanian, "The Greening of Industry: Achievement and Potential," in Norman J. Vig and Michael E. Kraft (eds.), *Environmental Policy in the 1990s,* 3rd ed. (Washington, DC: Congressional Quarterly).

Resource Conservation and Recovery Act (RCRA), Public Law 94–580, 94th Congress, 2nd session, October 21, 1976.

Ringquist, Evan J. (1995), "Evaluating Environmental Policy Outcomes," in James P. Lester (ed.), *Environmental Politics and Policy: Theories and Evidence,* 2nd ed. (Durham, NC: Duke University Press).

Rosenbaum, Walter A. (1995), *Environmental Politics and Policy,* 3rd ed. (Washington, DC: Congressional Quarterly).

Style, Robert (1993–1994), "Are State Laws Motivating Business to Pursue Pollution Prevention?" *Pollution Prevention Review* 4(1), pp. 61–70.

Sullivan, Robin M. and Donald W. Floyd (1991), "Pollution Prevention Planning: An Analysis of Statutory Structure for Successful Policy Implementation," *The Environmental Professional* 13, pp. 293–304.

U.S. Environmental Protection Agency (EPA) (1976), "Effective Hazardous Waste Management (Non-Radioactive) Position Statement," *Federal Register* 40(161) (August 18), pp. 35050–35051.

Varian, Hal (1992), *Microeconomic Analysis,* 3rd ed. (New York: W. W. Norton).

Vig, Norman J. and Michael E. Kraft (eds.) (1994), *Environmental Policy in the 1990s: Toward a New Agenda* (Washington, DC: Congressional Quarterly).

Waterman, Richard W. and B. Dan Wood (1993), "Policy Monitoring and Policy Analysis," *Journal of Policy Analysis and Management* 12(4), pp. 685–699.

White, Halbert (1984), *Asymptotic Theory for Econometricians* (New York: Academic Press).