LIABILITY RULES FOR HAZARDOUS WASTE MANAGEMENT: EFFICIENCY AND EQUITY EFFECTS

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"If you are planning for a year, sow rice,
If you are planning for a decade, plant trees,
If you are planning for a lifetime, educate a person."
- Kuan-Tze

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CHAPTER I

INTRODUCTION

Ever since the late 1970s, when the nation first learned of the dangers of buried hazardous waste through cases like New York's Love Canal, hazardous waste issues have been high on the environmental policy agenda. The intent of this policy is twofold: (1) to facilitate the cleanup of existing unsafe waste disposal sites, and (2) to avoid the creation of new unsafe sites.

Traditions in both law and economics suggest that making hazardous waste generators fully liable for all of the costs associated with waste disposal and clean-up will achieve these policy purposes. Policy makers, especially in Europe, often call this the Polluter Pays Principle (PPP). The primary example of the PPP in economics is the Pigouvian tax on polluters.

The policy of full liability for waste generators seems like a fair assignment of costs; that is, many people believe that polluters "should" pay the full cost of pollution. The assignment of full liability also appears to be an efficient assignment of costs. Perfect-Pigouvian taxes (when the tax per unit equals marginal external cost), for instance, will produce an efficient volume of waste.

There is more, however, to both equity and efficiency as part of this issue. On the equity side, what counts is not the legal or statutory incidence of costs, but, rather, who actually bears the costs. From the language of the tax incidence analysis of public finance, there is a difference between the legal and actual incidence of the policy. On the efficiency side, the assignment of full liability may induce waste generators to choose illegal, rather than legal, means of disposal. If it does, the assignment of full liability to waste generators does not necessarily produce an efficient allocation of resources. It also potentially changes the distribution of costs and benefits, making the equity aspects of the policy of full liability even more uncertain.

Objectives

In this study, we examine the relationship between the assignment of liability for costs of waste disposal and the volume of illegal disposal, using the basic principles of welfare economics. We determine the liability assignment, or share, that maximizes economic welfare when waste generators choose between legal and illegal disposal options. To capture the equity aspects of the issue, we construct a weighted social welfare function, where the weights reflect the interests of the principal groups affected by the liability rules.

The findings of this research will be of interest to economists who are concerned about applying Pigouvian taxes in real-world settings. The research findings should also be applicable to several policy alternatives currently being considered by federal policy makers.

Previous Studies

Three types of literature have been reviewed as background for this study: (1) federal statutes relating to hazardous wastes, (2) legal literature on the doctrines of tort liability, including strict liability, joint and several liability and common law, and (3) legal and economics literature on the effects of liability rules. A lengthy discussion of this literature appears in Chapter II.

The important relationship between legal and illegal disposal has been examined in two articles by Sullivan (1986, 1987). The relationship between Pigouvian taxes (a means of placing liability on waste generators) and equity has been developed in an unpublished paper by Willett (1993). This study extends Sullivan's analysis to include explicit consideration of the illegal market for waste disposal and the distribution of the costs and benefits of alternative liability assignments. This study applies Willett's insights on distribution to the case where waste generators can choose legal or illegal disposal.

Problem Statement

The disposal of hazardous waste often creates external costs. Economic theory indicates that there will be a more efficient allocation of resources if waste generators are required to pay these costs. Generators can be made to pay either through the assignment (and enforcement) of full liability, or through payment of a Pigouvian tax.

The basic question addressed in this study is whether these policies maximize social welfare. We examine two reasons why these policies may not produce an allocation of resources that maximizes social welfare. The first reason is that full liability creates an incentive for illegal waste disposal, thereby changing the costs and benefits associated with hazardous waste disposal. The second reason is that the assignment of liability affects the distribution of costs and benefits among affected parties. These distribution effects could change the level of social welfare even if there were no change in the level of costs and benefits. It is possible that the assignment of liability for external costs will change both the level and the distribution of costs and benefits. Thus, the optimal assignment of liability to waste generators may be a share less than, or greater than, full liability for external costs.

The results of this study indicate that the assignment of full liability of waste disposal costs to waste generators will not necessarily maximize a standard unweighted social welfare function. The assignment of full liability to waste generators may also fail to maximize a weighted social welfare function, one in which the costs and benefits associated with the assignment of liability are weighted by who pays and who benefits.

Methods

The research methods for this study consist of 5 steps:

1. the development of a geometric model of the legal and illegal markets for hazardous waste which illustrates the mechanics of partial equilibrium analysis for the 3 principal affected groups: consumers of waste disposal services (the waste-generating firms), producers (the waste disposal managers), and pollutees (the victims of the external costs associated with hazardous waste disposal);
2. a mathematical reformulation of the geometric model and determination of the first-order conditions for welfare maximization;

3. derivation of the optimal volume of waste disposal and the optimal liability placed on the waste generators;
4. development of an applied model of the legal and illegal markets for industrial hazardous waste, based on key parameters derived from government publications and economic theory;
5. calculation of the optimal liability shares for a set of plausible parameter values; and
6. discussion of the implications of these calculations for policy makers and future researchers.

Organization of the Study

An overview of the relevant literature pertaining to this study will be presented in Chapter II. This review covers essential environmental legislation, relevant liability rules, and the essence of Pigouvian taxes.

Chapter III contains the theoretical models of the legal and illegal markets for hazardous waste. Chapter IV provides a description of the actual market for industrial hazardous waste. Chapter V presents the findings of the calculations of the optimal liability share based on a range of plausible values for the parameters of the applied model. Chapter VI discusses the implications of the findings of this study for policy makers and future researchers.

CHAPTER II

LITERATURE REVIEW

This study examines the relationships between liability for environmental damages, economic efficiency, and economic welfare. The rules of liability are codified in the environmental statutes, and the effects of liablility rules on economic efficiency have been examined in both the legal and economics literature. Accordingly, this review begins with an overview of the environmental statutes and then proceeds to an overview of the legal and economic studies that are most relevant to this study.

Federal Environmental Statutes

The comprehensive environmental legislative package crafted by Congress in the 1970's deals with most aspects of environmental control. Nearly all of the major environmental programs administered by the federal government were addressed in that decade.

General Statutes

The Clean Air Act of 1970, as amended,[1] requires industry, after an initial planning period by the states, to control emissions of certain designated air pollutants by installing expensive, energy intensive air pollution control equipment. It also requires the control of certain toxic air pollutants.

The Clean Water Act of 1972, as amended,[2] requires the federal government to establish effluent criteria for categories of industry and compels industry to obtain permits for each point source discharge of pollutants to navigable waters. The levels of control technology which industry must install become increasingly stringent over time, making necessary periodic investments in water pollution control equipment.

The Safe Drinking Water Act of 1974 resulted in the establishment of maximum contaminant levels of certain substances permissible in drinking water supply for public consumption.[3]

The Toxic Substances Control Act of 1976 regulates the introduction into commerce of new chemical substances and the testing of certain existing chemical substances to determine their potential environmental impact when distributed in commerce.[4] It also provides the requisite authority for a comprehensive regulatory program dealing with disposition of polychlorinated biphenyls.

Hazardous Waste Statutes

The final piece of major environmental legislation enacted during the 1970's was the Resource Conservation and Recovery Act of 1976 (RCRA),[5] which, in a sense, was Congress' effort to deal with environmental toxins not covered by the other statutes. In contrast with the previous laws, RCRA deals with the residues collected in pollution control equipment in addition to many other waste streams generated by traditional manufacturing processes.

Briefly, the general requirements of RCRA regulations are as follows:

1. All facilities have to determine if any of the wastes they generate, transport, treat, store or dispose of meet the definition of "hazardous waste."[6]
2. Once it is determined that hazardous wastes are being handled at a particular facility, the next step is to categorize the facility as a generator, transporter, storer, treater or disposer of these wastes.
3. After determining that hazardous wastes are being managed in a facility, specific regulatory standards must be met:
    - (a) Generators of hazardous waste have to obtain an identification number from the Environmental Protection Agency (EPA), and must properly package, label, mark and store containers of toxic wastes, and use a manifest when the hazardous wastes are shipped off-site.[7] A generator is also precluded from storing such waste for more than 90 days without qualifying to operate as a hazardous waste storage facility.
    - (b) Transporters of hazardous waste must obtain an identification number and comply with substantial record keeping requirements, including the use of a manifest.[8]
    - (c) Facilities that treat, dispose of, or store hazardous wastes are required to meet a rigid set of standards in order to obtain a permit from EPA, including waste analysis plans, training requirements, contingency plans, record keeping, periodic reporting, financial responsibility for

closure and post-closure care and the use of a manifest for receiving hazardous waste shipments.[9]

In 1984, Congress amended RCRA adding significant new requirements. Rigid deadlines were placed on EPA for the issuance of permits to facilities that treat, dispose of, or store hazardous wastes (TDSFs).[10] Substantial limitations were imposed on the use of land disposal facilities for certain toxic materials.[11] In addition, within RCRA, Congress established a corrective program similar to the clean-up requirements of the Comprehensive Environmental Response, Compensation and Liability Act, as both an enforcement option before a permit is issued[12], and as a mandatory condition in all hazardous waste permits for TDSFs.[13]

This corrective action program will place a substantial financial burden on any facility that needs a permit under RCRA since it allows EPA to require the clean-up of any solid waste management unit located at the facility whether or not that unit ever handled toxic wastes. The legislative theory behind the corrective action requirement is the notion that EPA should not issue RCRA permits to TDSFs that have on-site contamination problems from any source.

Given this general review of the RCRA hazardous waste regulatory program that, for the most part, applies prospectively from 1980, industry has received a clear mandate as to their obligations with respect to toxic wastes now being generated. Hazardous waste must be managed with the same care and concern as products under RCRA, and industry must control toxic waste activities and reduce the quantity and toxicity of the wastes generated.[14]

The enforcement provisions of RCRA are contained in section 3008 of the Act. When the EPA finds that an individual is in violation of any requirement of the Act, it may issue an order requiring compliance or may seek an injunction from a court for the same purpose.

In the event the violator fails to take corrective action within the time specified, he/she is liable for civil penalties of up to $25,000 per day. The Act also provides for criminal sanctions for those who knowingly handle toxic waste without a permit or who falsify required reports or records.[15]

Criminal penalties include fines of up to $50,000 per day of violation, or up to two years in prison, or both. Further, section 3008 provides for additional criminal penalties if a violation of the Act is known by the perpetrator to have placed another person in imminent danger of death or serious bodily injury. The penalties for this type of violation ran as high as $250,000 and up to five years in prison for individuals, and $1,000,000 for organizations.

It may not be enough to rely on the periodic inspection by government representatives to assure compliance. Instead, a comprehensive self-policing program was mandated. The Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA)[16] as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA)[17] is the fruit of this mandate.

CERCLA is remedial, as opposed to RCRA which is regulatory in nature. Its objective is to provide the federal government with the authority and funds to clean up chemical spills and toxic waste sites. CERCLA establishes a hazardous substance response trust fund by imposing certain new taxes to enable the federal government to finance the clean-up of priority sites. It also provides a mechanism for identifying these sites on a national priorities list included as part of the national contingency plan.[18]

EPA is allowed to undertake removal actions at sites; however, these clean-ups are limited to costs of less than $2,000,000 per year.[19] CERCLA also allows EPA to undertake a remedial investigation to identify the environmental problems at a site, and a feasibility study to evaluate available remedies on the basis of cost-effectiveness.[20]

After the studies are completed, EPA prepares a record of decision, selecting the remedy. Public comment on the remedy is solicited before it becomes the final decision of EPA. Once this stage is reached, and in many cases earlier, potentially responsible parties (PRPs) considered liable by EPA have the opportunity to undertake the clean-up.

SARA changed the complexion of the program. Congress now requires EPA to establish clean-up standards, setting out legislative preferences and taking away some of EPA's discretion to determine "how clean is clean" on a case-by-case basis.[21] The statute also now allows EPA to develop cost allocation schemes instead of forcing PRPs to do it among themselves.[22]

Liability Under CERCLA. Liability for the past, present, or future disposal of hazardous wastes is governed by CERCLA. Subsection 107 (a) of CERCLA defines the responsible party as:[23]

(1) The owner and operator of a vessel, or any person who at the time of disposal of any hazardous substance owned or operated any facility at which such hazardous substances were disposed of (operator),

(2) any person who by contract, agreement, or otherwise arranged for disposal or treatment, or arranges with transporter for transport for disposal or treatment, of hazardous substances owned or possessed by such person, by any other party or entity, at any facility owned or operated by another party or entity and containing such hazardous substances (generator), and

(3) any person who accepts or has accepted any hazardous substances for transport to disposal or treatment facilities or sites selected by such person (transporter), from which there is a release, or a threatened release which causes the incurrance of response costs, of a hazardous substance, shall be liable for (A) all costs of removal or remedial action incurred by the United States Government or a state not inconsistent with the national contingency plan; (B) any other necessary costs of response incurred by any other person consistent with the national contingency plan; and (C) damages for injury to, destruction of, or loss of national resources, including the reasonable costs of assessing such injury, destruction, or loss resulting from such a release.

Subsection 107(b) of this act provides that there shall be no liability for a person otherwise liable who can establish by a preponderance of the evidence that release of a hazardous substance and the damages resulting there from were caused solely by: (1) an act of God; (2) an act of war, or (3) an omission of a third party other than: (a) an employee or agent of the defendant or (b) one whose act or omission occurs in connection with a contractual relationship.

Subsection 107(c) of CERCLA provides that there is no limit to a responsible party's liability for response costs or damages if: (1) the release or threat of release was the result of willful misconduct or willful negligence, (2) the primary cause of the release was violation of applicable safety, construction, or operating standards or regulations, or (3) such person fails or refuses to provide all reasonable cooperation and assistance requested by a responsible public official in connection with response activities under the national contingency plan.

A potential responsible party (PRP) may choose to defend an action brought pursuant to CERCLA by arguing that its hazardous substances are not the cause of the problem. There are at least three levels of defense. The first defense is where a particular PRP's hazardous substances went to the hazardous waste facility from which there is presently a release of hazardous substances, but the government is unable to prove that the particular generator's wastes are presently at the facility. The second defense is where the PRP sent waste to the hazardous waste facility and it is present at the facility, but there is no evidence that the particular PRP's wastes are leaching from the site. The third defense is the situation where the PRP sent hazardous substances to the facility, those substances remain at the facility, and those substances are leaching, but are not the substances that are creating the need for particular response costs. This potential responsible party has the argument that the response costs are not caused by its waste.

Strict Liability. Congress did not define the standard of liability under CERCLA, leaving this to the discretion of the courts. Examples of strict liability cases are: *State* *of New York v. Shore Realty Corporation* and *United States v. Conservation Chemical Company*.[24]

In *State of New York v. Shore Realty Corporation* 759F, the court held that: (1) state's response costs must be paid by the owner; (2) injunctive relief under CERCLA was not available to the state; (3) based on New York public nuisance law, injunction could be issued against defendants; and (4) stock holders and officers of the corporation were liable as an operator under CERCLA. In *United States v. Conservation Chemical Company*, 589 F. Supp., the court ruled that, under CERCLA, past off-site generators of hazardous waste were among those potentially liable for clean-up costs, and that such generators would be held to a standard of strict liability subject only to affirmative defenses listed in the statute.

Joint and Several Liability. Congress also did not define the standard of joint and several liability, leaving this to the decision of the courts. Examples of joint and several liability cases are: *United States v. Chemical Dyne Corporation* and *United States v. A and F Materials Company*.[25]

In *United Sates v. Chemical Dyne Corporation* 572 F. Supp. 809, the court held that joint and several liability could be imposed although it is not expressly provided for in CERCLA. In *United States v. A and F Materials Company*, Inc 578 F. Supp. 1249, the court ruled that (1) the intent of Congress was to impose joint and several liability under CERCLA; (2) Congress intended under CERCLA to create a standard of liability and to rely on courts to determine this liability under common law.

Other Sources of Liability. Apart from these liabilities imposed by statute, anyone in the hazardous waste management business must recognize that there are well-established common law theories that can form the basis for recovery by plaintiffs for personal injury and property damage. The following are common law theories for which there is a substantial body of existing site law upon which lawsuits could be and, in fact, are being based.

Negligence. Negligence is "conduct which falls below the standard established by law for the protection of others against unreasonable risk of harm." The law has long recognized that if a person discharges pollutants negligently and, as a result, someone else suffers personal injury or property damage, a cause of action may be maintained for the damages caused as a result.

Trespass. Trespass involves interference with a person's possessory interest in land. Most states recognize that one who pollutes the environment so as to cause physical damage to another's property is liable for the resulting damages in a trespass action.

Nuisance. A private nuisance is an unreasonable interference with another's use and enjoyment of his or her land, or related personal or property interest. A public nuisance is one which involves interference with a general public right. A civil cause of action may be maintained on either type of nuisance.

Strict Product Liability. There is a growing trend to hold parties strictly liable for the consequences of their actions involving hazardous materials. Strict environmental liability is related in concept to strict product liability. Just as a manufacturer may be held strictly liable for injuries caused by a defective product, firms which manage hazardous materials similarly may be held strictly liable if those materials escape and cause injury.

Most recently, additional theories of toxic tort liability are being advanced with the aim of easing the plaintiff's burden. These doctrines include those of alternative liability and enterprise liability.

Alternative Liability. Alternative liability may be applied in situations where two or more defendants acted in a way that may have caused injury to the plaintiff, but it is not possible to tell which of their actions in fact was the cause. Today, this theory is being applied in the environmental damage context.

Enterprise Liability. Enterprise liability addresses the situation where an industry-wide practice may be harmful. If it can be established that an entire group breached its obligation to the plaintiff, as a result of which he was injured, and through no fault of his own he is unable to identify which member or members of the group actually caused the injury, the entire group may be jointly and severally liable. This enterprise group could include the contractor who designed or constructed a waste site or who participated in a waste site clean-up action.

Economic Evaluations of Liability Rules

Economic studies concerned with efficient pollution control have traditionally devoted most of their attention to analyzing the effects of legislative or regulatory policy instruments, such as effluent taxes or pollution standards (Buchanan and Tullock, 1965; Baumol and Oates, 1971; Hochman and Zilberman, 1978; White and Wittman, 1979; Thomas, 1980; Dewees, 1983; Braulke and Endres, 1985; De Meza, 1989; Kolstad, Ulen, and Johnson, 1990; Helfand, 1991; Willett, 1993). With the exception of a relatively small number of articles (Lands and Posner, 1980; Opaluch, 1984; Sullivan, 1986; Dechert and Smith, 1988; Tietenberg, 1989; and Fox, 1991), the role of the court system in general and liability rules in particular have not received analytical attention in economic literature in proportion to their importance in resource allocation.

An early attempt to analyze the economic aspects of multiple tort feasers was the study by Lands and Posner (1980). The focus of their argument was the distinction between what the paper calls simultaneous and successive joint torts.

Lands and Posner developed a theoretical framework of liability for simultaneous joint torts of both joint and alternative-care types. Their paper showed that in the joint-care case (where efficiency requires both parties to take care) the common law rule of "no contribution" is efficient, and in the alternative case (where efficiency requires one but not both parties to take care) the common law rule of indemnity is efficient. In the special case where the costs of taking care are the same for both parties, the common law rule would be inefficient.

Lands and Posner also showed the same result in a parallel area of tort law which relates to the choice between contributory and comparative negligence in cases where efficiency requires the victim as well as the single or multiple injurers to take care. Finally, they analyzed the case of a separable tort and a successive joint tort. For all of those cases, they demonstrate scenarios which create motives for all parties to behave efficiently under a negligence standard.

Opaluch (1984) examined the use of liability rules in controlling toxic substance accidents, reviewing strict liability with particular emphasis on its role in hazardous/toxic pollution events. He demonstrates the success or failure of liability rules for providing economic incentives for pollution controls by the means of a simple conceptual model.

Opaluch concluded that several difficulties with current regulations lead to less than complete financial responsibility for damages from pollution accidents. In addition, he argued that inappropriate expectations concerning the probability of accidents may lead to imperfect internalization, especially in the case of low probability events. Simulation results also showed that excessive confidence in current technology can lead to large environmental costs. This may happen both through underestimated probabilities of accidents and through insufficient updating of these probabilities as new information accumulates.

Opaluch's conclusions may be interpreted as consistent with two recent trends, which should assist potential responsible parties (PRPs) in their efforts to gain some relief from current regulation. First, in March 1986, the Reagan Administration released the report of the Tort Policy Working Group on the causes, extent, and policy implications of the current crises in insurance availability and affordability. In commenting on the ills of joint and several liability, the report stated:

> Joint and several liability thus frequently operates in a highly inequitable manner - sometimes making defendants with only a small or even de minimus percentage of fault liable for 100% of the plaintiff's damage. Accordingly, joint and several liability in the absence of concerted action has led to the inclusion of many "deep pocket" defendants such as government, large corporations, and insured entities whose involvement is only tangential and who probably would not have joined except for the existence of joint and several liability (Tort Policy Working Group, p. 64).

Second, several provisions of SARA arguably bless the Gore Amendment approach. Under CERCLA, Section 122 (e), the EPA is authorized to submit the names and addresses of PRPs to each other, the volume and nature of hazardous substances contributed to the toxic waste facility by each PRP, and the ranking of PRPs by volume.[26] Thus, SARA authorizes EPA to provide a nonbinding preliminary allocation of responsibility among the PRPs.[27] Moreover, Section 122(g) allows EPA to settle with de minimis generators or innocent land owners.[28]

White and Wittman (1979) broadened the analysis of pollution control measures by considering their implications both for efficient abatement between a fixed polluter and pollutee (short-run efficiency) and for the incentives they set up for creation of an efficient spatial location pattern (long-run efficiency). Their article theoretically analyzed the role of liability rules and pollution taxes as alternative policies to correct environmental degradation.

White and Wittman developed the following conceptual framework: *X* denotes the smoke from a single polluter which damages a single pollutee, *Y*; *D* denotes the amount of pollution damage to *Y* expressed in dollars, and *D* depends on the dollar amount of an input,*x*, used by *X* in damage prevention, and the dollar amount of an input,*y*, used by *Y* for protection.. The more that *x* or *y* are used, the less damage that occurs. Each input is assumed to have diminishing returns in reducing damage, and land uses are assumed to be fixed at their locations.

In the long run, most land uses are not fixed at their current locations. Thus, in some cases, spatial separation is a more efficient means of reducing pollution than is on-site abatement. White and Wittman assumed that all pollutees are in perfectly competitive industries and that the prices of their outputs are exogenously determined in national or regional markets. They then defined an amount W_i as the maximum that the i^{th} land user can pay for an unpolluted site which is otherwise identical to the polluted site near the polluter's facility.

White and Wittman asserted that there are two basic factors defining a liability rule. The first is the decision rule (court rule) that determines when the polluter is liable to the pollutee for damages, and the second is the rule that sets the dollar amount to be paid. They then considered several liability rules defined by these two factors.

Consider first a set of liability rules under which the polluter, if found liable, must pay the actual dollar amount of damages incurred by the pollutee. The article argued that liability for actual damages (*LAD*) is a common standard in nuisance cases. However, polluters may either be strictly liable or liability may be based on a variety of negligence standards. The strict liability (*SL*) version of the *LAD* rule is $LAD/SL = D(x,y)$, where the polluter is liable wherever damage occurs, regardless of whether or not he or she acted to reduce pollution.

Another *LAD* rule makes the polluter liable for damages only if negligent, where negligence is defined as failure to meet a specified level of due care. White and Wittman assumed that X is liable for the actual damage incurred by Y if the level of X's pollution abatement input, x, is below the socially optimal level, x^*. X is not liable otherwise. They expressed this as:

$$LAD/N = D(x,y), \text{ if } x<x^*; \text{ or } LAD/N = 0 \text{ otherwise.}$$

The article viewed negligence as an economic concept; that is, the polluter is negligent if he uses less than the socially optimal amount of his own pollution abatement input.

The second part of the discussion focused on another liability rule which makes the polluter liable for the optimal cost (*LOC*) of pollution abatement by the pollutee, plus remaining damages (*R*). In this regard, X's liability does not depend on actual damage, but on optimal damage and prevention costs, given x. They expressed this rule as:

$$LOC/SL = D[x; R(x)] + R(x).$$

White and Wittman pointed out that rules based on optimal rather than actual behavior are relatively unfamiliar in economics but are common in various areas of the law where they are known as the doctrine of avoidable consequences or mitigation of damages. For example, in nuisance law if a field is swept by sulphur fumes making all crops unprofitable, the polluter is liable for the loss of profit to the farmer arising from no crop being grown. However the polluter is not liable for the greater loss incurred by the farmer if he plants and cultivates a hopeless crop. The negligence version of *LOC* the paper argued can be expressed as:

$LOC/N = D[x, R(x)] + R(x)$, if $x<x^*$, or $LOC/N = 0$, otherwise.

Establishing the short run efficiency properties of liability rules given a fixed polluter and a fixed pollutee, White and Wittman assumed Cournot behavior by each party, i.e., each treats the other's current level of pollution abatement input as fixed. They found that the result of the *LAD/SL* rule is not short-run efficient because the pollutee has no incentive to prevent damage by using input y. However the *LAD/N* rule does lead to short-run efficiency.

Turning to the optimal cost liability rules, White and Wittman argued that under strict liability (*LOC/SL*) the polluter minimizes his total private costs - which are now equal to the sum of the cost of his abatement input plus the optimal amount of abatement input by *Y* plus residual damages to *Y*. Thus all costs are internalized by *X* and the polluter's cost minimization point is the same as society's. Therefore, the polluter will choose x^* and the pollutee will choose y^*.

To examine the long run efficiency properties of the *LAD/N* case, they assumed that the polluter is the fixed land user and that two pollutees are bidding for a site nearby. The i^{th} land user's willingness-to-pay for polluted land is $W_i - [D^i(x^{i*}, y_i^*) + y_i^*]$. This expression simply says that land rent must fall by an amount equal to the private cost of pollution to the pollutee, efficiently abated, in order for the ith land user to be able to produce at zero profit at the polluted site.

Since the *LAD/N* rule is short-run efficient, any arbitrary polluter-pollutee pairs have incentives to abate pollution efficiently. White and Wittman (1979, p. 26) stated:

> Therefore land owners rent land to the highest bidder. The land market thus capitalizes the private cost of pollution into the price of polluted land, as well as the value of other site specific characteristics, to the highest bidder.

The authors then raised the question, "Is this an efficient result in the long-run?" The answer was "not necessarily". They argued that the liability rule for negligence (*LAD/N*) leads to correct long-run results in some cases but not in others. This is because the land market capitalizes the private cost of pollution to the pollutee, but not the social cost of pollution. Thus, the landowner has an incentive to select land uses for which the polluter's cost of abatement is inefficiently high and the pollutee's cost is inefficiently low.

For the *LOC/N* rule, the paper stated a willingness-to- pay by the ith pollutee for the polluted site as: $W_i - \{D^i\ [x^{i*}, R^i(x^{i*})] + R^i(x^{i*})\}$. Since $R^i(x^{i*}) = y_i^*$, it is apparent that willingness-to-pay is the same under the *LOC/N* rule as under the *LAD/N* rule. White and Wittman then concluded that neither rule consistently leads to efficient results in the long run.

For the *LOC/SL* rule, the article reported slightly different long-run results. Under this rule, willingness- to-pay by the ith pollutee for the polluted site becomes: $W_i\ -[D^i(x^{i*}, y_i^*) + y_i^*] + D^i[x^{i*}, R(x^{i*})] + R^i(x^{i*})$. It can be noted here that the pollutee's willingness-to-pay falls by an amount equal to the private cost of pollution efficiently abated, but rises by the amount of the damage payment expected from the polluter. Therefore, under a strict liability rule with the polluter's location fixed, the paper concludes that:

> There is no tendency for more pollution-sensitive land users to be outbid for polluted sites by less pollution-sensitive users. This suggests that strict liability rules, such as the *LOC/SL*, in general have less favorable results for long-run pollution control than do negligence rules such as the *LOC/N* or *LAD/N* (White and Wittmann, p. 26).

Calfee and Craswell (1984) examined the effects of uncertainty on the economic incentives of parties subject to a legal rule. The difficulties facing courts attempting to determine the optimal level of care, and the small likelihood that the negligence test will induce efficient behavior, are the main issues of concern.

Calfee and Craswell suggested that even an uncertain rule can be adjusted to produce the efficient level of compliance; however, the information needed to calculate and implement the proper adjustment seems to be complex. The paper also analyzed three effects of taking extra precautions when defendants are faced with an uncertain legal standard. First, overcompliance may raise a defendant's private costs because compliance is usually costly. Second, overcompliance may reduce the damages the defendant's behavior causes to others, in turn reducing the amount that the defendant will have to pay if found liable. Third, the extra care will increase the chance that the defendant will not be found liable at all, and thereby increase the likelihood that the social costs of the defendant's behavior will be borne by the victim rather than by the defendant.

Dechert and Smith (1988) used a hypothetical model to see how economic incentives encourage firms to comply with current and future environmental standards. The model firm produces a product that is sold in a competitive market and generates toxic wastes as a by-product. The analysis assumes that the firm knows the present treatment standard and can comply with it if it so wishes. It is also assumed that the hazardous waste is produced in fixed proportions that relate to the firm's market output. Thus, in this framework, the firm has two decisions to make: (1) how much waste to produce; and (2) what level of treatment to apply.

Dechert and Smith reported the preliminary findings of their study for stable and rising standards cases. Their results suggest that liability rules can impact the waste management industry in diverse ways.

Tietenberg (1989) examined the use of the joint and several liability doctrine as a means of financing the restoration of hazardous waste sites. This doctrine has played an important role in the control of toxic substances.

Tietenberg explores the efficiency criteria of civil suits, examining doctrines which comprise the tort law. The theme of this paper is built around the criterion that each party potentially involved in an incident should take additional precautions until the marginal cost of the additional care is equal to the marginal reduction in expected damage. The incentives for precautionary behavior, however, depend crucially on whether the parties to the incident are held strictly liable or judged by a negligence test.

Tietenberg constructed a noncooperative game model for his analysis. The players in this analysis are the set of PRPs and government. The government's strategic choice involves selecting which PRPs to sue, using the predetermined standard of care as established by precedent, while each PRP's strategic choice involves selecting its level of precaution.

The government's objective in this game is specified as maximizing its net litigation benefits subject to its budget constraint. Net litigation benefits are defined as the level of damages recovered from the litigants minus the cost to the government of litigation. Each PRP's objective, on the other hand, is to minimize its total costs, considering both its cost of precaution and its expected liability payments.

The solution employed in this paper is the Nash equilibrium where, given the choices of all other players, no player could improve his or her situation by choosing another feasible strategy. In pure strict liability, the government's Nash equilibrium strategy, the article argues, would be to target all PRPs for litigation that passed a positive net benefits test. If the amount of money recovered from a particular PRP is less than the government's costs of litigating, that PRP would fail the net benefits test.

With strict liability the absence of a negligence test means that each party must directly trade off extra precautions with resulting reductions in expected damage. Tientenberg concluded that, "whereas the level of damage assessment was not a significant factor in determining the Nash-equilibrium under negligence, it becomes very important under strict liability" (p. 312).

With respect to joint and several liability, Tietenberg argues that suing more parties than necessary to secure the full amount of damages would raise litigation costs with no commensurate benefit. Thus, the government's Nash-equilibrium strategy would be to target the wealthiest PRPs, to assure that damages could, and would, be paid.

The major concern of Fox (1991) was to study the issue of successor liability of corporate firms and its application under CERCLA. In this paper, a producer, *P*, takes an activity subject to strict liability that creates a risk of harm to others. The activity harms *V*. Before the harms become apparent, *P* sells its assets to *S* for cash and dissolves. The problem is this: should *V* be entitled to compensation from *S* in *P*'s stead?

Fox goes to considerable lengths to cover economic concepts such as efficient allocation of resources and efficient allocation of risk, together with some legal concepts. The paper rests on two standard assumptions employed in many economic models.The first assumption is that every participant in the economy, though lacking perfect foresight, knows the probability of all possible future events. The second assumption is that *P*'s management acts to maximize current share value. Current share value equates the present value of the aggregate expected future stream of dividends and other distributions accruing to the shareholders.

Fox developed a simple model of the sharing of an exogenous risk of loss. In this model the society consists of two individuals, *S* and *Y*, and a single discrete loss, *L*, with a probability of *P*. *W* and *W-L* represent society's total wealth with and without losses.

Fox defines Xn and Yn as X's and Y's respective levels of wealth if the loss does not occur (so that $Xn + Yn = W$), and $X1$ and $Y1$ as the corresponding levels of wealth if the loss does occur ($X1 + Y1 = W\text{-}L$). If $X(x)$ and $Y(y)$ are x's and y's respective utility functions, their respective expected utilities, EX and EY, are: $EX = (1\text{-}P)X(Xn) + PX(X1)$, and $EY = (1\text{-}P)Y(Yn) + PY(Y1)$.

The initial allocation of risk of loss for this model is Pareto efficient if and only if there is no reallocation that, after recompense to the party taking on more risk from the party taking on less, would make one party better off without making the other party worse off. This condition, in marginalist language, may be written as the ratio of X's marginal utility from his wealth level if the loss does not occur to his marginal utility from his level of wealth if it does occur. That is: $X'(Xn)/X'(X1) = Y'(Yn)/Y'(Y1)$.

In the next stage, Fox modified his simple model by stressing the possible loss of an exogenous event with a specified magnitude and probability, to reflect the fact that the possible loss is the result of P's actions - actions that can ultimately be traced to consumers' decisions to use P's products. In both models, however, a failure to provide compensation will cause the Pareto test to fail because the shift of risk will leave someone worse off. Fox's solution to this problem is the application of the Kaldor-Hicks efficiency criterion - where a reallocation would satisfy the Pareto test if compensation from the party benefitted to the party harmed would be adequate even if compensation is not paid. The rationale for using this criterion, Fox argued, is that the loser, despite his loss, is better off living in a world guided by it than in a world where no reallocation is permitted unless there is compensation.

Fox also considered a successor liability rule (in certain situations, courts have imposed such liability), one in which management faces the same expected reduction in what is available to its shareholders if it decides to engage in potentially harmful activity, whether or not it subsequently sells its assets and dissolves. He stated that: "the possibility of the sale of assets/ dissolution scenario does not affect the harmful activities' expected cost to shareholders, and private cost will again equal social cost" (p. 197).

The final section of the paper deals with another theme of Fox's study, namely, a general approach to successor liability and the case of CERCLA. One interesting aspect of this section is that the equity component is considered together with the efficiency criterion. At the outset, one should recognize that there are some arguments for and against broader successor liability that are largely unpersuasive. First, there is no way that a sale-of-assets successor in an arms-length deal can have benefited from the manner of disposal that gives rise to the predecessor's liability. Therefore, an argument that it is fair for the successor to be liable because he enjoyed such a benefit is clearly invalid. For example, in the Smith Land Case, the U.S. Court of Appeals made this sort of argument.[29] In dicta, it stated that where a choice must be made between the taxpayers and the successor corporation, the successor should bear the cost because the successor and its shareholders benefited from the manner of disposal.

Second, there is no way that a corporate successor maximizing share value can pass along to its current customers liability for its predecessor's past acts. A liability payment would be a fixed cost. Profits are maximized by choosing the level of output at which marginal cost equals marginal revenue, neither of which is affected by fixed cost.

This condition is true whether the industry is competitive or the successor has some degree of monopoly power. Therefore it is invalid to argue that

> imposing liability on a successor is fair because it will not harm the successor but rather will retrieve money from a group - the consumers - that benefited in the past from the low prices that the use of hazardous practices permitted (Fox, 1991, p. 216).

Fox also added that, for the same reasons, it is invalid to argue that imposing liability on a successor is a way of spreading losses over the large number of persons constituting the successor's consumers.

With regard to efficiency criteria, the general approach indicates that a rule imposing successor liability with respect to a given activity does yield benefits in terms of promoting efficient allocation of resources and risk. How big those benefits are depends on the extent to which management is aware of both the chance of liability and the chance of a sale of assets/dissolution scenario.

There is evidence that it is particularly difficult for both individuals and organizations to process and take account of risks that are remote in terms of probability and time. Therefore:

> a rough comparison between the remoteness of a typical products liability claim and a CERCLA claim would be helpful in deciding whether the case for successor liability under CERCLA is stronger than with products liability (Fox, 1991, p. 217).

Unlike products liability risks, where at least both parties know that the product is in the hands of the public and the product itself is easily open to examination, CERCLA liability may arise from an association with a third party and involve a dump owned by a fourth. Even if a buyer can trace these connections and is allowed to make tests, the costs are substantial. Therefore "while potential buyers know that almost any asset acquisition today can involve a CERCLA risk, it is very hard to get a clear picture of the risk's dimensions" (Fox, 1991, p. 218).

The second cost factor is the size of the possible damage compared to the size of the acquisition. CERCLA claims have the tendency to be totally unrelated to, and potentially much larger than, the value of the assets acquired. Therefore, this feature also suggests that the cost of a rule imposing successsor liability for CERCLA claims might be unusually high in terms of the rules' effects on the transfer of assets to more productive hands.

Pigouvian Tax Literature

Laws and regulations are not the only way to improve the liability for environmental damages. Economists have long advocated taxes for this purpose. In this section we review this literature. The seminal suggestion for this approach was made by the British economist, Arthur C. Pigou (1932). The dominant economic argument implied by the Pigouvian tradition is the adoption of a system of unit taxes or subsidies to control pollution, where the tax on a particular activity is equal to the marginal social damage (i.e., the difference between its marginal social cost and marginal private cost).

Imposition of such a tax yields a Pareto-efficient resource allocation in a competitive system.

Pigouvian taxes rarely have been used in practice. Baumol and Oates (1971) listed two reasons why: (1) the social damage of pollution is difficult to measure, and (2) although the efficient tax should correspond to the optimal situation, available data are related only to the neighborhood of the economy's initial position. They reviewed the nature of these difficulties and then proposed a substitute solution to the externalities problem.

This alternative, which they called the environmental pricing and standards procedure, sets an arbitrary standard of environmental quality and then imposes taxes to attain this standard. Even though their solution is not necessarily Pareto-efficient, it achieves the desired limit on pollution, given the level of output, at a minimum cost to the economy. This approach decreases the information required for decision making.

To minimize information costs, Baumol and Oates suggested an iterative procedure in which policy makers adjust the tax per pollution unit by increasing or decreasing it whenever the actual level of pollution is above or below the predetermined level.

Hochman and Zilberman (1978) utilized a model based upon Johansen's (1972) production theory framework to investigate pre- and post-determined levels of pollution, as well as pollution abatement technologies. Their basic model contains a competitive industry with micro units that produce one homogenous output. Each micro unit is characterized by a fixed-proportions production function and an output capacity. It uses one variable input, such as labor, and generates pollutants in fixed proportion to its output. The fixed labor-output ratio is denoted by L, and the fixed pollution-output ratio is denoted by Y.

For the predetermined case, Hochman and Zilberman used Baumol and Oates' (1971) proposed taxing and standards procedure. Their model verified that the iterative procedure yields a unique and stable equilibrium when the wage rate (w) is given but the firm influences its output price (p). The system is said to be in equilibrium when the market is cleared and the actual pollution equals the predetermined level.

For the post-determined case, they calculated the partial effects of changes in the tax, output price, and wage rate on average labor per output and pollution per output in terms of the conditional moments of distribution, the output price, and the elasticity of supply with respect to price. They argued that the effects of the changes are not conclusive, and depend on the specific forms of the distributions. For instance, one would expect that an increase in the tax rate will always result in a reduction of the average pollution.

Finally Hochman and Zilbermann extended their model to include a more realistic pollution abatement method for production units. These units allocate part of their variable input to activities such as collecting of the pollutants generated during the production process, preventing leakages, and hauling the accumulated waste to a disposal area. Each production unit is characterized by three coefficients: L_1 - the labor/output ratio,Υ - the pollution/output ratio, and L_2 - the abatement/labor ratio. The price of the variable input for both activities, production and abatement, is designated as w.

In a system supported by taxes, they argued that the entrepreneur chooses among three alternatives: (1) stop employing the production unit if $(p-L_1-\lambda\Upsilon) < 0$ and $(p-L_1w-L_2w\Upsilon) < 0$, (2) pay taxes if $L_2w > \lambda$ and $(p-L_1w-\lambda\Upsilon) \geq 0$, or (3) abate pollution if $L_2w < \lambda$ and $(p-L_1w-L_2w\Upsilon) \geq 0$, where λ is the tax per unit of pollution. Hochman and Zilberman derived the marginal values of parametric changes in λ, p and w in the appendix of their text, but they deduced the qualitiative results by verifying the effects of the parametric changes on the three boundary planes. For example, for a price and wage-taking industry, an increase in the tax level has two effects: (1) excluding taxpaying units with low quasi-rent and (2) transforming taxpaying units with relatively efficient abatement technologies into pollution-abatement units.

> The first effect reduces output, waste, and labor input; the second effect strengthens the reduction in waste while increasing the demand for labor. Thus, output and waste are reduced but the effect of all increases in taxes on the demand for labor is not conclusive (Hochman & Zilberman, 1978, p. 754).

Buchanan and Tullock (1965) developed a positive theory of externality control policy for both production and consumption interactions, which allowed them to isolate influences on policy formation which had been neglected. They argued that policy makers choose instruments that obtain the environmental target and meet with least resistance by polluters. Since tax revenues are not redistributed among polluters, and since in their model the total loss to polluters incurred by taxation is higher than the loss resulting from direct regulations, polluters may prefer the use of standards. In this context, Buchanan and Tullock suggest a two-parameter policy which consists of the mutual use of taxes and subsidies in order to reduce producers' losses.

White and Wittman (1979) considered the possibility of levying pollution taxes on pollutees as well as polluters. A tax on actual damages, TAD^X , represents a strict liability, *SL*, version of the tax, where the superscript *X* indicates that the tax is levied on the polluter. A modified version of TAD would make *X* liable only if he did not use the efficient level of his input, $x*$.

The article argued that no tax would be levied on the polluter if his abatement expenditures (x) were greater than or equal to x^*. If a polluter's expenditure level were below x^*, then the tax would be levied. This is similar to a negligence-based liability rule in that no payment would be required of firms engaging in efficient pollution abatement.

Based on optimal damages and abatement costs, analogous to the LOC rules, $TOC^X/SL = D[x, R(x)] + R(x)$ represents the strict liability version of the tax, where $Y = R(x)$ is again the optimal level of input y for any given level of input x. A third family of tax rules based on actual cost (TAC) is constructed as $TAC^X/SL = D(x,y) + y$. In this case the polluter is liable for actual damages plus the pollutee's actual prevention costs. The *TAC* can also be levied on the pollutee. The tax on the pollutee equals the actual cost of pollution prevention by the polluter. The strict liability version of this tax is $TAC^Y/SL = x$.

White and Wittman referred to the combination TAC^X/SL and TAC^Y/SL as a double tax and to the other taxes levied on the polluter alone as single taxes. They then concentrate on the long- and short-run efficiency properties of the *TAC* under Cournot behavioral assumptions.

First, under a pollution tax, the pollutee receives no damage payment from the polluter. Therefore his private cost is $D(x,y) + y$. The willing pollutee minimizes this expression over his choice of y, using more y until the last unit, which under White and Wittman's hypothetical example costs one dollar, leads to one dollar's worth of damage reduction.

White and Wittman argued that, from the polluter's point of view, no matter whether he pays the government via a tax, or the pollutee via a liability rule, cost is the same. Therefore he minimizes his private cost including tax. If the TAC^X is levied, polluter costs are $x + D(x,y) + y$. This cost is minimized by polluter (X), where the last unit of x, which costs one dollar, reduces X's private pollution costs by one dollar.

White and Wittman then consider the double tax combination of TAC^X and TAC^Y. From the polluter's viewpoint, they argued that liability is the same as before for any given level of x and y. However, the willing pollutee's private cost now includes a tax payment equal to x. Thus, his or her cost function including tax, $[D(x,y) + y + x]$, internalizes all the social costs of pollution. Since the tax payment is a fixed cost, the pollutee's incentive is still to use more y until the first order condition $(1 + Dy = 0)$ holds. Therefore the double tax has a Cournot equilibrium at x^*, y^* and is short-run efficient.

White and Wittman next considered the long-run efficiency effect of a pollution tax by assuming that the polluter is the fixed land user and that two industries are bidding for a nearby site. The ith land user's willingness-to-pay for polluted land may be expressed as: $W_i - [D^i(x^{i*}, y_i^*) + y_i^*]$, which says that land rent must fall by an amount equal to the private cost of pollution to the pollutee, efficiently abated, in order for the ith land user to be able to produce without a loss at the polluted site.

It has been noted that all the single taxes are efficient in the short-run. This implies that any arbitrary polluter-pollutee pair has incentives to abate pollution efficiently. The landowner rents his land to the highest bidder. The land market thus capitalizes the private cost of pollution into the price of polluted land, as well as the value of other site-specific characteristics to the highest bidder.

White and Wittman posed the question, "Is this an efficient outcome in the long-run?" The answer is no, simply because the land market capitalizes the private cost of pollution to the pollutee, not the social cost of pollution. Therefore, the land owner has an incentive to select land uses for which the polluter's cost of abatement is inefficiently high and the pollutee's inefficiently low.

The authors turn next to double pollution taxes, by assuming that TAC^X/SL and TAC^Y/SL are levied on the polluter and pollutee, respectively. Then with the tax, the ith pollutee's willingness-to-pay for the polluted site is designated by: $W_i - [D^i(x^{i*}, y_i^*) + x^{i*} + y_i^*]$. The land owner has an incentive to sell the land to the pollutee with the highest willingness to pay. Since, with the tax, any pollutee's private cost of pollution equals social cost, the landowner has an incentive to choose the socially optimal land use near the polluting firm.

Thus, the double tax meets the twin criteria of short-run and long-run efficiency better than any of the alternatives. White and Wittman concluded: "While taxes and liability rules have about equivalent results in the short-run, double taxes work better in the long-run than either single taxes or simple liability rules" (p. 38).

Thomas (1980) addresses the question of the cost-effectiveness of a policy which provides economic incentives for pollution control (pollution taxes) vis-a-vis pollution regulations (mandatory pollution control expenditures, restrictions on the use of fuel, and a regulation as a function of fuel). He utilizes a model of joint production of a conventional output and pollutants which allows for continuous substitution between polluting fuels and nonpolluting inputs on the one hand, and balances pollution control inputs on the other.

Thomas used the steel industry as a case study to show the welfare cost under an efficient policy (tax) for reducing pollution, compared with that under alternative inefficient policies (i.e., mandatory pollution control). His results suggest that substantial cost savings can be made by following the optimal policy.

Dewees (1983) attempts to exhibit the failure of market policies of proven efficiency. As Kneese and Schultze (1975) pointed out, the efficiency advantage of market policies equating marginal control costs among sources is only relevant for a perfectly-mixed or point-source environment. For widely dispersed polluters, the marginal benefits of abatement will vary with location, so marginal costs should vary as well. The issue of concern with Dewees' research was the study of direct short-term effects of industrial pollution control policies on the affected firms, or more precisely the shareholders of affected firms, and their employees. To accomplish this task, the paper applied a simple competitive model to three alternatives: pollution tax, pollution right, and pollution standard. Dewees' study, however, was an investigation of previous research which demonstrated that polluting firms should prefer pollution quotas to pollution taxes, and that they may prefer pollution quotas to no pollution policy at all (Buchanan and Tullock, 1975).

Dewees showed that shareholders of existing firms will prefer pollution standards to pollution charges or pollution rights, because the standards raise prices less and cause fewer plant closings than the market-like policies. Labor, on the other hand, will prefer no pollution control policy; but if controls are to be applied, labor will prefer standards that are tougher for new plants than for old plants over any other policy. Both pollution taxes and the sale of pollution rights generate revenues that could be used to compensate those hurt by the pollution. In many cases the ability to compensate is equal to the value of free rights.

In another microeconomic context, Braulke and Endres (1985) posed an interesting question: Can a pollution tax be counterproductive? Based on their comparative static results, they showed that this is indeed possible, even if the polluting firm is competitive and faces conventionally sloped demand and input supply curves.

De Meza (1988) of the London School of Economics argues that, although Braulke and Endre's discussion is suggestive, it does not actually prove that there exist configurations of preferences and technology that produce perverse responses. He directed his research to question the practical relevance of Braulke and Endres' result.

De Meza's study accomplished its task by demonstrating that a pollution tax increases pollution only in a Marshalian unstable context. He further showed that this, in turn, requires exceptional behavior on the part of suppliers of inputs.

In a study of ex post liability for harm versus ex ante safety regulation, Kolstad, et al. (1990) introduced risk and uncertainty in a legal standard setting. They utilized a model of marginal and total cost of a risk-neutral firm engaging in a risky business. They then analyzed several legal propositions and their mathematical proofs.

They showed that these propositions have profound implications in a wide range of public policies for dealing with external costs, both in conditions where ex ante regulation should be used alone or both ex ante regulations and ex post liability rules should be used jointly. The paper demonstrates that, where there is uncertainty, there is inefficiency associated with the exclusive use of negligence liability, and ex ante regulation can correct the inefficiency.

Helfand (1991) reviewed the effects of five different forms of pollution standards (standard as a set level of emissions; standard as emissions per unit of output; standard as emissions per unit of a specified input; standard as a set proportion of total output; standard as a set amount of a specified input) on input decisions, the level of production, and firm profits. She demonstrated for a one-firm profit maximizing model that a direct restriction on pollution leads to the highest level of profits and efficiency when all pollution standards are set to achieve the same level of emissions.

Among her conclusions, the following is notable: a mandate for use of a pollution-abating input leads to highest output, followed by standards for pollution per unit of output or input; and a restriction on production reduces output most, followed by a restriction on the polluting input.

Willett (1993) shows how the trade-offs between economic efficiency and economic equity might be addressed when environmental pollution is internalized with a tax. The paper provides a general equilibrium analysis of a tax system, which in considerable detail explains the identification of the alternative distributions of economic welfare between affected groups: consumer, producer, taxpayer, and victim (pollutee). Willett constructed a weighted social welfare function to capture the distributional impacts and used it to find the optimal tax rate for given values of the welfare weights that were assumed to be set exogenously.

The final study reviewed is that of Sullivan (1986). The issue of concern in this paper is the assignment of responsibility for the cleanup of unsafe hazardous waste disposal sites. The author explores the efficiency effects of different liability rules and poses the following question: For what fraction of the clean-up costs should waste generators be liable? Sullivan argues that the current EPA policy is designed to assign full liability to waste generators. He suggests that this assignment of liability is somewhat inefficient since it encourages illegal waste disposal activity on the part of the waste generator. He shows that, in the cases where the optimal liability requires assignment of less than full costs on the waste generator, it is necessary to subsidize the generator out of tax revenues. This produces some welfare costs of taxation, and tends, as a consequence, to increase the proportion of costs assigned to the waste generator. The optimal assignment, then, is determined by examining the trade-offs between gains in efficiency occasioned by reduced illegal dumping and the losses due to increased taxes.

CHAPTER III

THEORETICAL MODELS

The development of an analytical framework for investigating the efficiency and equity trade-offs of liability rules for hazardous waste management requires two major steps: (1) modeling firm and industry behavior for disposition and clean-up of hazardous waste, and (2) quantification of this behavioral model. This chapter contains both a geometric and mathematical model of the hazardous waste market.

Geometric Model

The micro-level model for this analysis considers an industry that generates toxic waste as a by-product of its production process. Firms in the industry have the opportunity to choose two methods of waste disposal, namely legal and illegal. For the purpose of this research we will refer to them as legal and illegal markets.

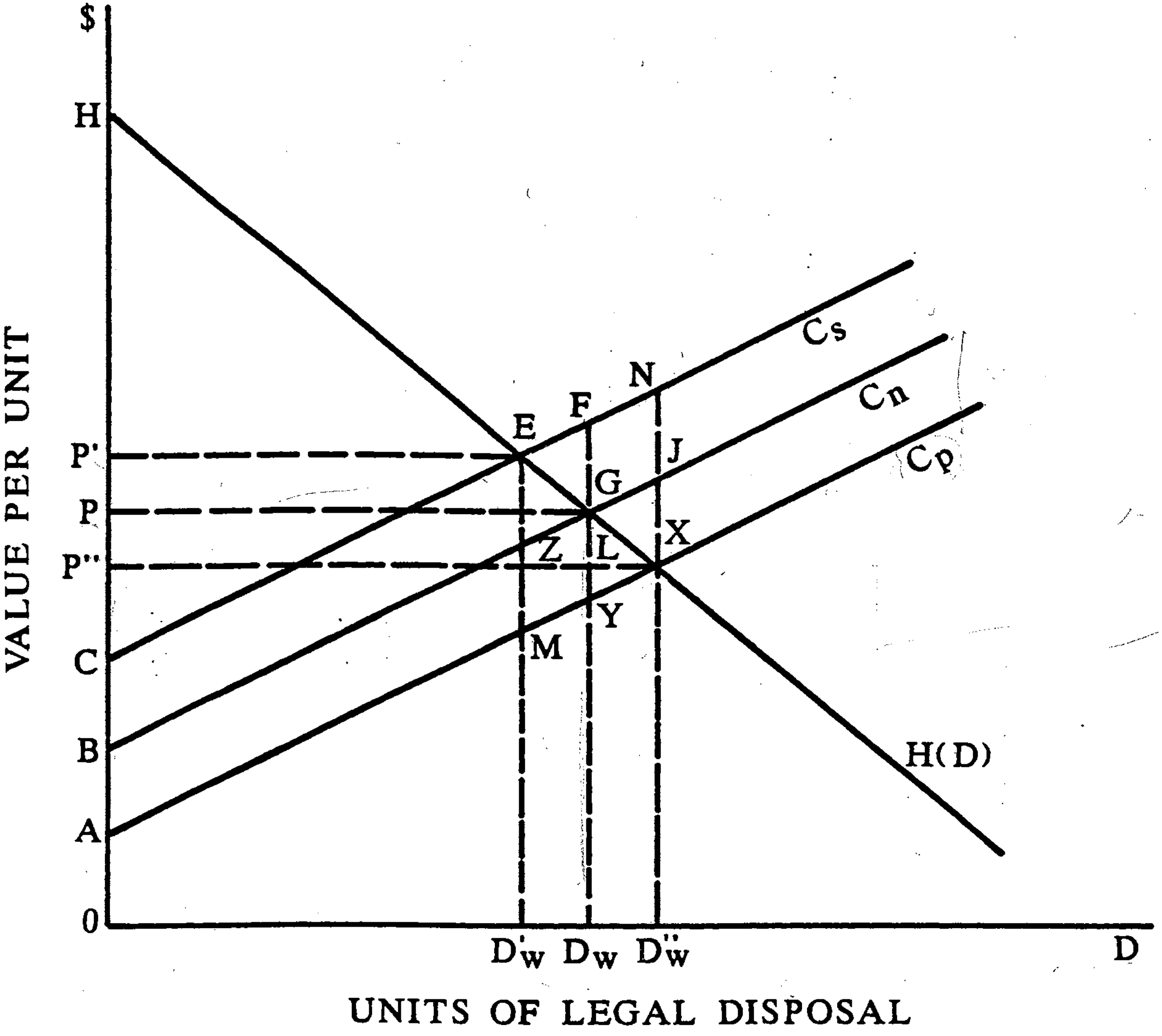
Public policy determines the price of legal waste disposal directly. But the price of illegal waste disposal depends indirectly on the enforcement policy. More enforcement will increase the expected cost of illegal disposal, decreasing the volume of illegal disposal. The policy generates efficiency gains by decreasing the environmental costs from illegal disposal.

Legal Waste Disposal Market

Consider first the determination of waste disposal in a legal market. This market is illustrated by Figure 1. Let C_p represent the marginal private cost of waste disposal, C_s the marginal social cost of waste disposal, and $H(D)$ the demand for legal waste disposal services. Point X is the market equilibrium if only the marginal private cost of waste disposal is covered by the waste generator. The equilibrium price and quantity are then P'' and D_W'', respectively. But if the full marginal externality cost is covered by the waste generating firm along with the marginal costs, then market equilibrium occurs at point E with equilibrium price P' and quantity D_W'.

An intermediate situation can also arise in the market for legal waste disposal as shown in Figure 1. It is possible that the waste generating firms will pay all of the marginal private costs of waste disposal but only a fraction of the marginal externality cost. This possibility is represented by the C_n schedule shown in Figure 1. The market equilibrium now occurs at point G with an equilibrium price of P and equilibrium quantity of D_W. It is assumed in the remaining discussion that point X represents the initial equilibrium, and that point G describes the equilibrium point in the legal disposal market created by policy.

Three different groups are represented in Figure 1: (1) firms which produce waste requiring waste disposal services, (2) firms that supply waste disposal service, and (3) individuals adversely impacted by the marginal externality costs related to the legal waste disposal activity - pollutees or "victims." Each of these groups is examined in detail in the following paragraphs.



LEGAL DISPOSAL MARKET
FIGURE 1

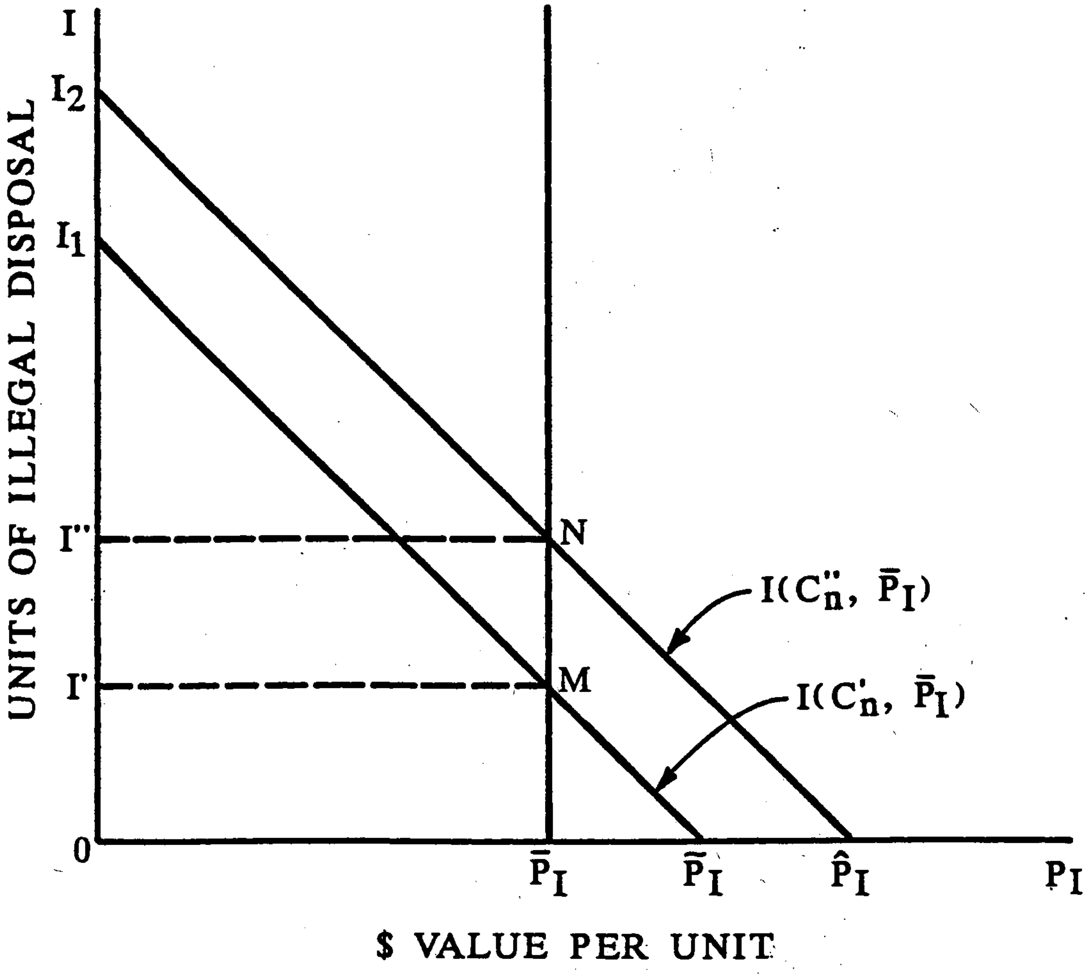
Consider first the impact on firms with a demand for waste disposal services. Increasing the market price from P'' to P means that the consumers of waste disposal services experience a loss in consumer's surplus equal to the area $P''PGX$. The suppliers of waste disposal services in contrast now provide D_W units of waste disposal services and charge a price of P. This results in a revenue transfer from consumers to suppliers equal to the area $P''PGL$. But these suppliers experience a reduction in the level of waste disposal services provided in this market equal to the distance $D_W'' D_W$. This, in turn, implies a loss in producers' surplus equal to the area $-BPG + AP''X$.

The third impact is concerned with externality costs. If legal waste disposal activity is equal to D_W'', the associated level of externality cost is equal to the area $CNXA$. But if the level of disposal is D_W, then the associated level of externality cost is $CFYA$. The net impact on external cost of reducing the volume of legal waste disposal from D_W'' to D_W is equal to the area $FYXN$.

Illegal Waste Disposal Market

This market is illustrated by Figure 2. It is hypothesized that waste generators have demand for illegal as well as legal waste disposal. This implies, moreover, that these waste generating firms receive benefits from having access to illegal disposal.

The demand for illegal waste disposal is assumed to depend on two factors: the policy cost of illegal waste disposal and the policy cost of legal waste disposal paid by the waste generator, C_n - C_p. The policy cost of illegal waste disposal is assumed to be



ILLEGAL DISPOSAL MARKET
FIGURE 2

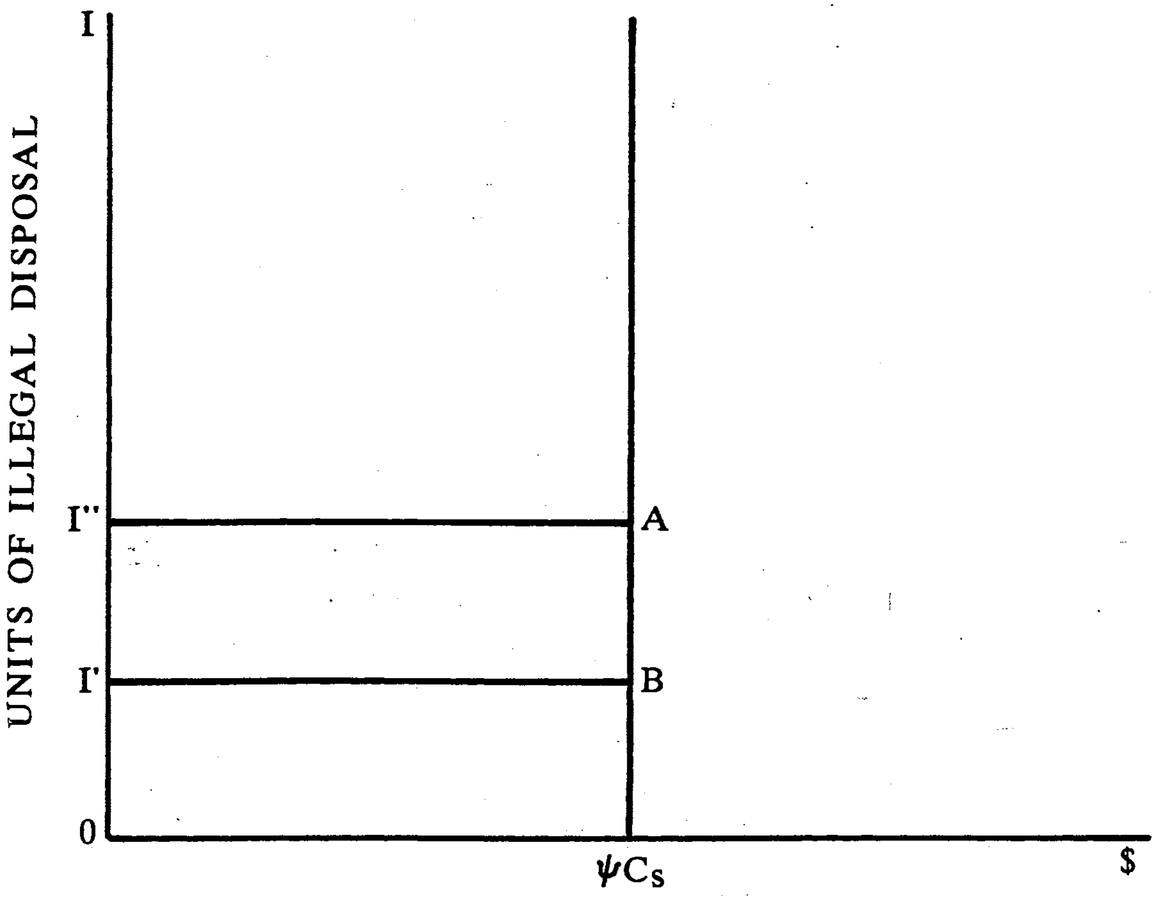
determined by governmental enforcement programs. Such costs are exogenously determined in this analysis.

The policy cost of legal waste disposal paid by the waste generators is determined in the legal market, as indicated. Increasing the policy cost of legal waste disposal paid by the waste generator causes the demand for illegal waste disposal to shift to the right. That is, legal and illegal waste disposal are related as substitutes.

The consequences of changes in the market for illegal disposal are shown in Figure 2. $\bar{P}_I$, the policy cost of illegal disposal, is assumed to be constant in this situation. Increasing the cost of legal disposal to the waste generator means that the demand for illegal disposal increases from I' to I''. When the demand for illegal disposal is $I(C'_n, \bar{P}_I)$, total benefit for the waste generating firm is equal to area $OI'M\tilde{P}_I$, while the total cost of illegal disposal is equal to area $OI'M\bar{P}_I$. This implies a net benefit equal to $\bar{P}_I M\tilde{P}_I$.

But if demand is $I(C''_n, \bar{P}_I)$, then total benefit is $OI''N\bar{P}_I$, and total cost is $OI''N\bar{P}_I$. This implies a net benefit of $\bar{P}_I N\tilde{P}_I$.? Thus, increasing the demand for illegal waste disposal from I' to I'' implies that the waste-generating firms receive an increase in net benefit equal to the area $\tilde{P}_I MN\bar{P}_I$.

Illegal waste disposal activities also imply the possibility of environmental damage which is associated with marginal externality costs as well. Discussion and measurement of these costs are based on Figure 3.



EXTERNAL COST PER UNIT

EXTERNAL COST IN THE ILLEGAL MARKET
FIGURE 3

The marginal externality cost of illegal disposal consists of two components. The first is the volume of illegal disposal. In Figure 3, there are two volumes: I' associated with P'' in Figure 1 and I'' associated with P in Figure 1.

The second component is the cost of the resources required to make the external effect harmless to third parties affected by illegal disposal. These costs are assumed to be a single value per unit; that is, the per unit cost is assumed to be ψC_s, where ψ measures illegal disposal costs as a fraction of legal disposal costs; ψ can be greater than one. The exact relationship between ψC_s and P_I (price of illegal waste disposal) is not known on an a priority basis. The welfare loss associated with illegal waste disposal, on the extra units occurring because of the price rise from P'' to P in the legal market, is shown by the area $I'I''AB$ in Figure 3. This area is an accurate measure of minimum welfare losses, provided that third parties in the illegal market value a cleaner environment as highly as the cost of clean-up.

Mathematical Model

We begin this section by identifying the following terms:

R_1: Net welfare effects to waste-generating firms as consumers of waste disposal services.

R_2: Net welfare effects to firms supplying legal waste disposal services.

R_3: Net welfare effects to all victims of pollution.

Let us specify each term separately. Following Figures 1 and 2, the net welfare effects for waste generators can be stated as follows:

(3.1) $R_1 = -P''PGX + \tilde{P}_I MN\hat{P}_I .$

Note that $P''PGX$ has a negative sign representing a loss in consumers' surplus. Areas appearing in the right-hand side of the expression (3.1) are defined as follows:

From Figure 1:

(3.2) $P''PGX = P''PGL + GLX$

and

(3.3) $GLX = GD_W D''_W X - LD_W D''_W X$

The area ***P"PGL*** can be restated as: $P''PGL = OPGD_W - OP''LD_W$

or

(3.4) $P''PGL = H(D_W) \cdot D_W - P''D_W .$

The area $GD_W D''_W X$ can be approximated by $\int_{D_W}^{D''_W} H(D)dD$ and the area $LD_W D''_W X$ can be measured by $P''(D''_W - D_W)$. Thus,

(3.5) $GLX = [\int_{D_W}^{D''_W} H(D)dD - P''(D''_W - D_W)] .$

Substituting expressions (3.4) and (3.5) into expression (3.2) yields:

(3.6)
$$P''PGX = [H(D_W) \cdot D_W - P''D_W] + [\int_{D_W}^{D''_W} H(D)dD - P''(D''_W - D_W)] .$$

From Figure 2:

(3.7) $$\tilde{P}_I MN\hat{P}_I = \bar{P}_I N\hat{P}_I - \bar{P}_I M\tilde{P}_I$$

The areas $\bar{P}_I N\hat{P}_I$ and $\bar{P}_I M\tilde{P}_I$ can be approximated as follows:

(3.8) $$\bar{P}_I N\hat{P}_I = \int_{\bar{P}_I}^{\tilde{P}_I} I(C''_n, P_I)dP_I$$

and

(3.9) $$\bar{P}_I M\tilde{P}_I = \int_{\bar{P}_I}^{\hat{P}_I} I(C'_n, P_I)dP_I .$$

Substituting expressions (3.8) and (3.9) into expression (3.7) yields:

(3.10) $$\tilde{P}_I MN\hat{P}_I = \int_{\bar{P}_I}^{\tilde{P}_I} I(C''_n, P_I)dP_I - \int_{\bar{P}_I}^{\hat{P}_I} I(C'_n, P_I)dP_I .$$

We can now substitute expressions (3.6) and (3.10) into expression (3.1) to obtain the following:

(3.11)
$$R_1 = - [H(D_W) \cdot D_W - P''D_W] + [\int_{D_W}^{D''_W} H(D)dD - P''(D''_W - D_W)]$$
$$+ \int_{\bar{P}_I}^{\tilde{P}_I} I(C''_n, P_I)dP_I - \int_{\bar{P}_I}^{\hat{P}_I} I(C'_n, P_I)dP_I .$$

To calculate R_2, note that the initial equilibrium in the legal market prior to any policy action is P'' and D''_W, as shown in Figure 1. The initial producers' surplus, therefore, is shown by the area $P''XA$.

Next let us assume that some amount of liability is imposed on the consumers of waste disposal service. This amount is shown by the difference between lines C_n and C_p in Figure 1. A new market equilibrium is reached at point G. This means that the equilibrium point in the legal market is now given at point G. Thus, after the policy action the market price is P and equilibrium quantity is D_W. The producers' surplus in this case is area *PGB* in Figure 1.

The net welfare effects for producers is defined as the net change in producers' surplus that occurs when an increased share of the social cost for waste disposal is imposed on the consumers of these services. Thus we can state the change in producers' surplus resulting from an increase in the share from 0 to C_p - C_n as:

(3.12) $R_2 = -BPG + AP''X.$

The right-hand side of expression (3.12) can be written as follows:

(3.13) $BPG = OPGD_W - OBGD_W$

and

(3.14) $AP''X = AP''LY + LYX.$

Note that,

(3.15)
$$AP''LY = OP''LD_W - OAYD_W.$$

Substituting expression (3.15) into expression (3.14) yields:

(3.16)
$$AP''X = OP''LD_W - OAYD_W + LYX.$$

Now substituting expressions (3.13) and (3.16) into expression (3.12) yields:

(3.17)
$$R_2 = -OPGD_w + OBGD_W + OP''LD_W - OAYD_W + LYX.$$

Let us define the schedules for C_p and C_n in Figure 1 as $C_p(D)$ and $C_n(D)$, respectively. Using these functions, we can convert the geometric areas of expression (3.17) into the following:

(3.18)
$$OPGD_W = C_n(D_W) \cdot D_W$$

(3.19)
$$OBGD_W = \int_0^{D_W} C_n(D)dD$$

(3.20)
$$OP''LD_W = P''D_W$$

(3.21)
$$OAYD_W = \int_0^{D_W} C_p(D)dD$$

and

(3.22)
$$LYX = LD_W D''_W X - D_W YXD''_W.$$

The right-hand side of expression (3.22) can be written as follows:

(3.23) $$LD_W D''_W X = P''(D''_W - D_W)$$

(3.24) $$D_W\, YXD''_W = \int_{D_W}^{D''_W} C_p(D)dD.$$

Substituting expressions (3.23) and (3.24) into expression (3.22) yields

(3.25) $$LYX = P''(D''_W - D_W) - \int_{D_W}^{D''_W} C_p(D)dD$$

We can now substitute expressions (3.18) through (3.21) and (3.25) into expression (3.17) to obtain:

(3.26) $$\begin{aligned} R_2 = {} & -C_n(D_W)D_W + \int_0^{D_W} C_n(D)dD + P''D_W \\ & + P''(D''_W - D_W) - \int_{D_W}^{D''_W} C_p(D)dD . \end{aligned}$$

Following from Figures 1 and 3, the net welfare effects for victims of pollution can be stated as follows:

(3.27) $$R_3 = FNXY - I'I''AB .$$

The areas in the right-hand side of expression (3.27) can be further defined as follows:

from Figure 1:

(3.28)

$$FNXY = \int_{D_W}^{D''_W} [C_s(D) - C_p(D)]dD\,;$$

from Figures 2 and 3:

(3.29)

$$II''AB = \psi C_s[I(C''_n, \bar{P}_I) - I(C'_n, \bar{P}_I)]\,,$$

where ψC_s represents the externality cost per unit of illegal waste. $[I(C''_n \bar{P}_I) - I(C'_n, \bar{P}_I)]$ represents the change in the demand for illegal disposal for a fixed unit price of illegal disposal ($\bar{P}_I$).

Substituting expressions (3.28) and (3.29) in expression (3.27) yields:

(3.30)

$$R_3 = \int_{D_W}^{D''_W} [C_s(D) - C_p(D)]\ dD - \psi C_s[I(C''_n, \bar{P}_I) - I(C'_n, \bar{P}_I)]\,.$$

Social Welfare Weights

The determination of environmental policy (i.e., liability rules program) involves an implicit weighting of welfare gain and loss by consumers, producers and victims of pollution. Thus, one may hypothesize that environmental policy makers have a welfare function which includes social welfare weights for the three groups of individuals involved. This social welfare function can be written as follows:

$$W = \omega_1 R_1 + \omega_2 R_2 + \omega_3 R_3 \tag{3.31}$$

where ω_1, ω_2, and ω_3 are weights for consumers, producers, and victims of pollution, respectively; and R_1, R_2, and R_3 are the respective net welfare effects of the policy.

Optimal Liability Share. The ultimate objective of this modeling exercise is to determine the optimal liability share for the waste generator, where the optimal liability share, λ, is defined as the portion of $C_s(D) - C_p(D)$ which, if paid by the waste generator, will maximize the value of expression (3.31). This determination has two steps. First, an expression for the optimal volume of waste disposal (D_W) is established. Second, the optimal D_W is substituted into the expression $[H(D) - Cp(D)]/[Cs(D) - Cp(D)]$ to determine the optimal liability share for the waste generator.

The calculation of the optimal volume of waste disposal begins with the substitution of expressions (3.11), (3.26), and (3.30) into expression (3.31). This substitution yields:

$$\begin{aligned} W = & - \omega_1\{[H(D_W) \cdot D_W - P''D_W] + [\int_{D_W}^{D''_W} H(D)dD - P''(D''_W - D_W)]\} \\ & + \omega_1 [\int_{\bar{P}_I}^{\tilde{P}_I} I(C''_n, P_I)dP_I - \int_{\bar{P}_I}^{\hat{P}_I} I(C'_n, P_I)dP_I] \\ & + \omega_2 [-C_n(D_W)D_W + \int_o^{D_W} C_n(D)dD + P''D_W - \int_o^{D_W} C_p(D)dD \\ & + P''(D''_W - D_W) - \int_{D_W}^{D''_W} C_p(D)\,dD] \\ & + \omega_3 \{\int_{D_W}^{D''_W} [C_s(D) - C_p(D)]dD - \psi C_s [I(C''_n, \bar{P}_I) - I(C'_n, \bar{P}_I)]\} \end{aligned} \tag{3.32}$$

Expression (3.32) is the desired social welfare function for the problem outlined in Chapter I. We postulate that the volume of waste disposal, D_W, is determined so as to maximize expression (3.32). The first derivative of expression (3.32) is:

(3.33)

$$
\begin{aligned}
\frac{\partial W}{\partial D_W} = & - \omega_1 \{[\frac{dH(D_W)}{dD_W} \cdot D_W + H(D_W) - P''] + [- H(D_W) + P'']\} \\
& + \omega_1 [\int_{\bar{P}_I}^{\tilde{P}_I} \frac{\partial I}{\partial C''_n} (C''_n, P_I) \frac{\partial C''_n}{\partial D_W} dP_I - \int_{\bar{P}_I}^{\hat{P}_I} \frac{\partial I}{\partial C'_n} (C'_n, P_I) \frac{\partial C'_n}{\partial D_W} dP_I] \\
& + \omega_2 [- \frac{dC_n D_W}{dD_W} \cdot D_W - C_n(D_W) + C_n(D_W) + P'' - C_p(D_W) - P'' + C_p(D_W)] \\
& + \omega_3 \{ - [C_s(D_W) - C_p(D_W)] - \psi \frac{dC_s(D_W)}{dD_W} [I[C''_n(D_W), \bar{P}_I) \\
& - I(C'_n(D''_W), \bar{P}_I)] - \psi C_s(D_W) [\frac{\partial I}{\partial C''_n} (C''_n(D_W), \bar{P}_I) \frac{\partial C''_n}{\partial D_W} \\
& - \frac{\partial I}{\partial C'_n} (C'_n(D_W), \bar{P}_I) \frac{\partial C'_n}{\partial D_W}]\}
\end{aligned}
$$

Simplifying expression (3.33) yields:

(3.34)

$$
\begin{aligned}
\frac{\partial W}{\partial D_W} = & - \omega_1 [\frac{dH(D_W)}{dD_W} \cdot D_W] + \omega_1 [\int_{\bar{P}_I}^{\tilde{P}_I} \frac{\partial I}{\partial C''_n} (C''_n, P_I) \frac{\partial C''_n}{\partial D_W} dP_I \\
& - \int_{\bar{P}_I}^{\hat{P}_I} \frac{\partial I}{\partial C'_n} (C'_n, P_I) \frac{\partial C'_n}{\partial D_W} dP_I] - \omega_2 [\frac{dC_n(D_W)}{dD_W} \cdot D_W] \\
& + \omega_3 \{- [C_s(D_W) - C_p(D_W)] - \psi \frac{dC_s(D_W)}{dD_W} [I(C''_n(D_W), \bar{P}_I) \\
& - I (C'_n(D_W), \bar{P}_I)] - \psi C_s(D_W) [\frac{\partial I}{\partial C''_n} (C''_n(D_W), \bar{P}_I) \frac{\partial C''_n}{\partial D_W} \\
& - \frac{\partial I}{\partial C'_n} (C'_n(D_W), \bar{P}_I) \frac{\partial C'_n}{\partial D_W}]\}
\end{aligned}
$$

Solving expression (3.34) for the optimal volume of legal disposal yields:

(3.35)

$$D_W = \frac{\begin{array}{c}\omega_1\left[\int_{\bar{P}_I}^{\tilde{P}_I} \frac{\partial I}{\partial C''_n}(C''_n, P_I)\frac{\partial C''n}{\partial D_W} - \int_{\bar{P}_I}^{\hat{P}_I} \frac{\partial I}{\partial C'_n}(C'_n, P_I)\frac{\partial C'_n}{\partial D_W}\, dP_I\right. \\ + \omega_3\left\{ - [C_s(D_W) - C_p(D_W)] - \psi \frac{dC_s(D_W)}{dD_W}[I[C''_n(D_W), \bar{P}_I)\right. \\ - I\,(C'_n(D_W), \bar{P}_I)] - \psi C_s(D_W)\left[\frac{\partial I}{\partial C''_n}(C''_n(D_W), \bar{P}_I)\frac{\partial C''_n}{\partial D_W}\right. \\ \left.\left. - \frac{\partial I}{\partial C'_n}(C'_n(D_W), \bar{P}_I)\frac{\partial C'n}{\partial D_W}\right]\right\}\end{array}}{\omega_1 \frac{dH(D_W)}{dD_W} + \omega_2 \frac{dC_n(D_W)}{dD_W}}$$

To operationalize the model, we work with linear versions of the demand and cost functions. That is:

(3.36) $H(D) = H - \delta D.$

(3.37) $C_p = A + \alpha D$

(3.38) $C_s = C + \gamma D$

Subtracting expression (3.37) from (3.36), and rearranging the terms, yields:

(3.39) $(H - A) - (\delta + \alpha)\, D$

Subtracting expression (3.37) from (3.38) yields:

(3.40) $C + \gamma D - A - \alpha D = C - A$, when $\alpha = \gamma$.

The liability share, λ, that maximizes social welfare is determined by noting that the following holds true from Figure 1:

(3.41)
$$\lambda = \frac{H(D) - C_p(D)}{C_s(D) - C_p(D)}$$

Substituting expressions (3.39) and (3.40), when $D = D_W$, into expression (3.41) and rearranging terms, yields:

(3.42)
$$\lambda = [\frac{H - A}{C - A}] - [\frac{\delta - \alpha}{C - A}] \frac{\begin{aligned} &\omega_1 [\int_{\bar{P}_I}^{\tilde{P}_I} \frac{\partial I}{\partial C''_n}(C''_n, P_I) \frac{\partial C''_n}{\partial D_W} dP_I - \int_{\bar{P}_I}^{\tilde{P}_I} \frac{\partial I}{\partial C'_n}(C'_n, P_I) \frac{\partial C'_n}{\partial D_W} dP_I] \\ &+ \omega_3 \{- [C_s(D_W) - C_p(D_W)] - \psi \frac{dC_s(D_W)}{dD_W} [I(C''_n(D_W), \bar{P}_I) \\ &\quad - I(C''_n(D_W), \bar{P}_I) - \psi C_s(D_W) [\frac{\partial I}{\partial C''_n}(C''_n(D_W), \bar{P}_I) \frac{\partial C''_n}{\partial D_W} \\ &\quad - \frac{\partial I}{\partial C'_n}(C'_n(D_W), \bar{P}_I) \frac{\partial C'_n}{\partial D_W}\} \end{aligned}}{\omega_1 \frac{dH(D_W)}{dD_W} + \omega_2 \frac{dC_n(D_W)}{dD_W}}$$

The second-order condition for a maximization is:

(3.43)
$$\omega_1 \frac{dH(D_W)}{dD_W} - \omega_2 \frac{dC_n(D_W)}{dD_W} < 0.$$

Model Parameterization

It is clear from expression (3.42) that the optimal liability share depends on the value of a number of parameters. Values for each parameter are determined by a search of the literature on hazardous waste disposal, welfare economics, and public finance, as reported in Chapters IV and V.

Sensitivity Analysis

It is expected that a range of plausible parameter values will be found. Thus, it is necessary to do a thorough sensitivity analysis to determine the plausible range of values for λ. This analysis is reported in Chapter V, for non-marginal changes in λ. The effect of increasing or decreasing key paramaters on marginal changes in λ can be determined by inspecting equation (3.42). The results of this inspection are summarized in Table 3-1.

Table 3-1
Effects of Parameter Increases on λ

Parameter	Effect on λ
H	↑
δ	↓
A	↑
α	↑
C	↓
$\partial I/\partial C_n$	?
P_I	?
ψ	↓
ω_1	?
ω_2	↑
ω_3	?

Most of the effects on λ of larger values for the parameters in Table 3-1 are straightforward. The exceptions are $\partial I/\partial C_n$, P_I, and ω_3.

The larger $\partial I/\partial C_n$, the larger the quantity demanded of illegal disposal (I in Figure 2). The larger I is, the larger the consumers' surplus from illegal disposal (the term multiplied by ω_1 in the numerator of 3.42), and the larger the external cost of illegal disposal (the term multiplied by ω_3 in the numerator of 3.42). Larger values for consumers' surplus in the illegal market increase λ; larger values for external costs in the illegal market reduce λ. Therefore, the net effect on λ is ambiguous, *a priori*.

Larger values for P_I have just the opposite effects of larger values for $\partial I/\partial C_n$; they reduce the consumers' surplus from illegal disposal and reduce the external costs from illegal disposal. Smaller values for consumers' surplus in the illegal market reduce λ ; smaller values for external costs in the illegal market increase λ . The net effect on λ is, once again, ambiguous.

If ω_3 increases, it increases the external costs in both markets. Neither are desirable. However, the avoidance of higher external costs in the legal market requires an increase in λ, and the avoidance of higher external costs in the illegal market requires a lower λ. Whether the optimal λ should rise or fall cannot be determined, *a priori*.

CHAPTER IV

THE INDUSTRIAL HAZARDOUS WASTE MARKET

In this chapter, we summarize the limited information available on the legal and illegal markets for industrial hazardous waste, beginning with a definition of hazardous waste.

Definition of Hazardous Waste

Section 1004(5) of the Resource Conservation and Recovery Act[30] defines hazardous waste as solid waste, or a combination of solid wastes which because of its quantity, concentration, physical, chemical, or infectious characteristics may: (A) cause, or significantly contribute to an increase in mortality, or an increase in serious irreversible, or incapacitating reversible illness; or (B) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed.

Types of Industrial Hazardous Waste

Each year, United States industries generate substantial quantities of solid wastes as residual materials from basic manufacturing processes. Among these wastes are hazardous materials that pose present or potential danger to human health and the environment.

Table 4-1 shows summary data on 24 types of industrial hazardous waste substances. Among these substances, nonmetallic inorganic liquids and nonmetallic inorganic sludge are the largest group of wastes, producing 42 percent of the national total.

TABLE 4-1
ESTIMATED NATIONAL GENERATION OF INDUSTRIAL HAZARDOUS WASTE IN 1983, RANKED BY WASTE QUANTITY (In thousands of metric tons)

Waste Type	Estimated Range		Mean Quantity	Percent of Total
	Lower	Upper		
Nonmetallic Inorganic Liquids	68,102	96,420	82,261	31
Nonmetallic Inorganic Sludge	23,285	32,837	28,061	11
Nonmetallic Inorganic Dusts	19,455	22,784	21,120	8
Metal-Containing Liquids	14,125	25,394	19,760	7
Miscellaneous Wastes	14,438	16,393	15,415	6
Metal-Containing Sludge	13,246	15,748	14,497	6
Waste Oils	9,835	18,664	14,249	5
Nonhalogenated Solvents	11,325	12,935	12,130	5
Halogenated Organic Solids	9,321	10,246	9,784	4
Metallic Dusts and Shavings	6,729	8,738	7,733	3
Cyanide and Metal Liquids	4,247	10,520	7,383	3
Contaminated Clay, Soil, and	5,092	5,830	5,461	2
Sand	4,078	5,078	4,578	2
Nonhalogenated Organic Solids	4,035	4,438	4,236	2
Dye and Paint Sludge	3,451	4,585	4,018	2
Resins, Latex, and Monomer	2,965	4,502	3,734	1
Oily Sludge	2,774	4,185	3,479	1
Halogenated Solvents	2,866	4,003	3,435	1
Other Organic Sludge	2,179	2,305	2,242	1
Nonhalogenated Organic Sludge	508	933	720	a
Explosives	583	848	715	a
Halogenated Organic Sludge	537	577	557	a
Cyanide and Metal Sludge	19	33	26	a
Pesticides, Herbicides	1	1	1	a
Polychlorinated Biphenols				
Total	223,196	307,997	265,595	

Source: Congresssional Budget Office (1985)
a. Less than one percent

Nonmetallic inorganic dusts, metal-containing liquids and miscellaneous wastes are ranked third, fourth, and fifth, comprising 21 percent of the national total. Metal containing sludge, waste oils, nonhalogenated solvents and halogenated organic solids are ranked sixth, seventh, eighth, and ninth, contributing 20 percent of the national total waste. A host of other lesser wastes accounts for the remaining 17 percent.

Sources of Hazardous Waste by Industry

Table 4-2 presents the estimated national generation of industrial hazardous wastes ranked by major industry group for 1983. The chemical and allied products industry ranked first among the industries for hazardous waste generation with about 48 percent of the estimated national total.

TABLE 4-2
ESTIMATED NATIONAL GENERATION OF INDUSTRIAL HAZARDOUS WASTES RANKED BY MAJOR INDUSTRY GROUP (In thousands of metric tonss)

Major Industry	Estimated Quantity In 1983	Percent of Total
Chemicals and Allied Products	127,245	47.9
Primary Metals	47,704	18.0
Petroleum and Coal Products	31,358	11.8
Fabricated Metal Products	25,364	9.6
Rubber and Plastic Products	14,600	5.5
Miscellaneous Manufacturing	5,614	2.1
Nonelectrical Machinery	4,859	1.8
Transportation Equipment	2,977	1.1
Motor Freight Transportation	2,160	0.8
Electrical and Electronic Machinery	1,929	0.7
Wood Preserving	1,739	0.6
Drum Reconditioners	45	a
Total	265,595	100.0

Source: Congressional Budget Office (1985)
a. Less than one-tenth of one percent.

The primary metals industry contributed the second highest quantity of hazardous wastes, with about 18 percent of the estimated national total. The third largest generator of hazardous wastes, with an estimated 12 percent of the national total, was the petroleum products industry (i.e., predominantly oil refining plants).

Fabricated metal products, rubber and plastic products, and miscellaneous manufacturing each generated between 2 and 9 percent to the estimated national total. Nonelectrical machinery transportation equipment, motor freight transportation, electrical and electronic machinery, wood preserving and drum reconditioners had the lowest rates of hazardous waste generation in the country.

Sources of Hazardous Waste by State

Table 4-3 presents the distribution of hazardous wastes by state. Texas ranked first among the states for hazardous waste generation with about 13 percent of the national total. Ohio ranked second in hazardous waste generation with about 7.4 percent of the estimated national total. California ranked third among the states for waste generation with about 6.5 percent of the estimated national total.

Illinois, Louisiana, New Jersey, Michigan, Tennessee, Indiana, New York, Alabama, Missouri, Washington, and West Virginia each generated between 2 percent and 5 percent of the estimated national total. Alaska, Hawaii, Maine, Nevada, North Dakota, South Dakota, and Vermont had the lowest rates of hazardous waste generation in the country.

TABLE 4-3
ESTIMATED GENERATION OF INDUSTRIAL HAZARDOUS WASTE IN 1983, BY STATE
(In thousands of metric tons)

State	Quantity	Percent of National Generation	State	Quantity	Percent of National Generation
Alabama	6,547	2.5	Montana	662	0.2
Alaska	52	a	Nebraska	739	0.3
Arizona	642	0.2	Nevada	379	0.1
Arkansas	3,729	1.4	New Hampshire	431	0.2
California	17,284	6.5	New Jersey	12,948	4.9
Colorado	1,902	0.7	New Mexico	619	0.2
Connecticut	4,283	1.6	New York	9,876	3.7
Delaware	894	0.3	North Carolina	3,954	1.5
Florida	2,981	1.1	North Dakota	269	0.1
Georgia	3,338	1.3	Ohio	19,692	7.4
Hawaii	202	0.1	Oklahoma	2,673	1.0
Idaho	1,160	0.4	Oregon	969	0.4
Illinois	14,810	5.6	Pennsylvania	18,260	6.9
Indiana	10,189	3.8	Rhode Island	1,745	0.7
Iowa	1,774	0.7	South Carolina	3,669	1.4
Kansas	2,564	1.0	South Dakota	159	0.1
Kentucky	4,647	1.7	Tennessee	12,159	4.6
Louisiana	13,801	5.2	Texas	34,866	13.1
Maine	337	0.1	Utah	1,139	0.4
Maryland	2,989	1.1	Virginia	4,038	1.5
Massachusetts	4,536	1.7	Vermont	226	0.1
Michigan	12,399	4.7	Washington	5,523	2.1
Minnesota	2,212	0.8	Wisconsin	3,297	1.2
Missouri	6,046	2.3	West Virginia	5,642	2.1
Mississippi	1,816	0.7	Wyoming	572	0.2
			Total	265,595	100.0

Source: Congressional Budget Office (1985)

a. Less than one-tenth of one percent.

Waste Management Technologies

The intent of the Resource Conservation and Recovery Act (1976) is twofold: first, to promote the reuse or recycling of materials; and second, to protect public health and the environment from the risks of improper management of industrial hazardous wastes. In fact, because the 1976 act permitted industries to use relatively inexpensive land disposal technologies, it provided few incentives to promote the reuse and recycling of wastes. Moreover, relatively little progress has been made toward achieving the second goal. Industry has continued to rely on land disposal in facilities that will eventually contaminate groundwater and surface waters.

The Congressional Budget Office (1985) estimates that, in 1983, about 180 million metric tons, or 68 percent of all hazardous waste, were deposited in or on the land, encompassing the techniques listed in Table 4-4.

Injection well

Deep-well injection typically involves drilling a disposal passage into salt caverns or aquifers and pumping wastes through wells into these geologic formations. This technique is popular because more than adequate capacity is available, the cost of well disposal is relatively low, and fewer problems are associated with establishing an on-site injection well than with other facilities.

Sewer and Direct Discharge

Under this technique, the liquid wastes are discharged directly to sewers or surface waters. The General Accounting Office (1983) reported that substantial quantities of untreated wastes (such as cyanide and metal solutions) are released into the sewer systems of some municipalities or directly to waterways. This is because municipal

TABLE 4-4
WASTE QUANTITIES MANAGED IN 1983, RANKED BY MAJOR TECHNOLOGY
(In millions of metric tons)

Technology	Description	Quantity Managed	Percent of Total
Injection Well	Injection of liquid wastes into wells or salt caverns	66.8	25
Sewer and Direct Discharge	Discharge of treated and untreated liquids to municipal sewage treatment plants, rivers, and streams	58.9	22
Surface Impoundment	Placement of liquid wastes or sludges in pits, ponds, or lagoons	49.5	19
Hazardous Waste Landfill	Placement of liquid or solid wastes into lined disposal cells that are covered by soils	34.2	13
Sanitary Landfill	Placement of wastes in unlined dump sites, which normally receive only inert, nonhazardous materials	26.7	10
Distillation	Recovery of solvent liquids from other waste contaminants through fractional distillation	10.9	4
Industrial Boilers	Burning of wastes in industrial and commercial boilers as a fuel supplement	9.5	4
Oxidation	Chemical treatment of reactive wastes	3.0	1
Land Treatment	Biodegradation of liquid wastes or sludges in soils	2.9	1
Incineration	Burning of wastes in advanced technology incinerators meeting stringent environment standards	2.7	1
Ion Exchange	Recovery of metals in solution through membrane separative techniques	0.5	a

Source: Congressional Budget Office (1985)

a. Less than 1 percent

pretreatment systems and effluent standards for direct discharge, required under the Clean Water Act, are not yet in place everywhere or for all industries.

Surface Impoundments

Surface impoundments are depressions in the ground used to store, treat, or dispose of a variety of industrial wastes. They have a variety of names: lagoons, treatment basins, pits, and ponds. These depressions can be natural, man-made, lined, or unlined.

This technique poses risks because many impoundments have no liners to prevent waste seepage into surface water or groundwater, despite existing regulations requiring such protection. Surface impoundments can range from several feet in diameter to hundreds of acres in size.

Hazardous Waste Landfill

Landfill is placement of liquid or solid wastes into lined disposal cells that are covered by soil. Over time, fractions of the waste can be released from the landfill, either as leachate or as volatilized gases.

The objective of landfilling is to reduce the frequency of occurrence of releases so that the rate of release does not impair water or air resources. Some liquids are able to leak through compacted clays or synthetic lining materials. Reducing the potential for migration of toxic constituents from a landfill requires minimizing the production of liquid and controlling the movement of those that inevitably form.

Liquids can enter a landfill in several ways: by disposal of free liquid waste, by evolution from sludges and semisolids, from precipitation infiltrating through the cover into the landfill cell, and from lateral movement of groundwater infiltrating the sides or the bottom of the cell.

No one disputes the presence of liquids in a landfill. The objective of good landfill design is to control their movement. Flow of liquids through soil and solid waste occurs in response to gravity and soil moisture conditions.

When the moisture content within a landfill exceeds field capacity, liquids move under saturated flow and percolate to the bottom. Liquid movement under saturated conditions is determined by the hydraulic force driving the liquid, and the hydraulic conductivity of the liner material. Hydraulic force can result in discharge through a liner.

Landfills can be designed to reduce migration, but there is no standard design. Advanced designs would have at least the following features: a bottom liner, a leachate collection and recovery system, and a final top cover.

Sanitary Landfills

Sanitary landfills are unlined dump sites which normally receive only inert, nonhazardous materials. The majority of wastes disposed of in sanitary landfills in 1983 was composed of metallic and non-metallic dusts, generated chiefly by the primary metals, steel, and iron foundry industries. Most were disposed of adjacent to generating plants in compliance with existing federal and state regulations.

Distillation

Distillation is a mechanical processs designed to separate components from a liquid mixture because the components have different boiling points. This technique is often used to purify organic products or to separate by-products.

Industrial Boilers

This technical device is designed to burn wastes in industrial and commercial boilers as a fuel supplement. The boiler converts as much as possible of the heat of combustion of the fuel mix into energy used for producing steam.

Different types of boilers have been designed to burn different types of fuels. Boilers burn lump coal, pulverized coal, No. 2 oil, No. 6 oil, and natural gas. The predominant application to hazardous waste involves boilers of the kind that would normally burn No. 2 fuel oil.

Oxidation

Oxidation is a process that can destroy nonhalogenated organic waste (i.e., cyanides, phenols, mercaptans, and nonhalogenated pesticides). These processes are known in the commercial world as chemical devices for the treatment of reactive wastes.

Land Treatment

Land treatment is the process of biodegradation of liquid wastes or sludges in soils. Biodegradation processes have been used to treat conventional wastes for a century. This technique allows living microorganisms to decompose wastes by "eating" them and transforming them into water, carbon dioxide, and simpler, less dangerous molecules. Inorganic wastes are not destroyed by these processes; therefore, managers must use great care in applying biological treatments to inorganic compounds.

Another shortcoming of land treatment is that as the bacteria die, they form a sludge. The sludges have a reduced volume and associated hazard, but they may themselves be toxic. Sludges may contain some inorganic constituents (especially metals), so in many cases they must be sent for additional treatment or for disposal as toxic wastes.

Incineration

Incineration is not a new technology. Many municipalities used it to dispose of solid waste until the 1960s. During the 1970s, however, more stringent air-quality regulations forced incinerators to close, and new highway systems allowed easier access to landfill sites.

Nonetheless, incineration is now one of the officially favored ways to manage hazardous wastes because it can destroy most wastes completely. Although the wastes not destroyed may be highly toxic, the residual is small compared to the original volume. This method appears to eliminate most future environmental liabilities, although there is disagreement on this point (Commoner, Shapiro, Webster, 1987). Landfills, in contrast, shift risks to future generations.

Present incineration costs are generally much higher than the costs of placing wastes in landfills or deep wells. But as various wastes are banned from deep wells or landfills in the years ahead, incineration will become more competitive in spite of more stringent operating standards and emissions limitations.

Ion Exchange

This method tries to separate dissolved inorganic substances from an aqueous liquid. The liquid passes through layers of natural or synthetic resins, allowing ions in the resin to be exchanged with inorganics in the liquid. The electroplating industry uses ion exchange to extract chromium and cyanide ions. The process is also useful for treating certain solutions and dissolved salts.

The inorganics removed from aqueous waste streams may cause environmental damage. If the inorganics are hazardous, they must be deposited in a RCRA facility.

Location of Disposal Sites

According to a 1986 survey by the EPA, approximately 3,000 large-quantity generators accounted for 99 percent of the industrial hazardous waste managed by industry (EPA, 1987, p. 1-4). Somewhere between 70 and 98 percent of this waste is handled by the waste generating firms; the remainder is handled by commercial waste management firms (EPA, 1987, p. E5-4). These facilities are located primarily east of the Rockies, as is most of the waste-generating activity.

There is growing evidence that hazardous waste management facilities are located disportionately in proximity to non-white and low-income households (Bullard, 1983, 1984, 1990; Bullard and Wright, 1985; General Accounting Office, 1983; Commission for Racial Justice, 1987; EPA, 1992). This has led to a growing concern about environmental justice in facility siting.

The first event to focus national attention on environmental injustice occurred in 1982 when government officials decided to locate a polychlorinated biphenyls (PCB) landfill in predominantly black Warren County, North Carolina. This event led to a study by the General Accounting Office (1983) of the socioeconomic and racial composition of communities surrounding the four major hazardous waste landfills in the south. This study reported that three of the four were located in communities that were predominantly black.

The Warren County incident and the GAO report led the United Church of Christ's Commission for Racial Justice, a participant in the Warren County Protests, to sponsor a nationwide study in 1987 (Commission for Racial Justice, 1987). Based on sophisticated statistical methods, this study found that race and income are the two most important determinants of where commercial hazardous waste facilities are located.

Illegal Waste

The treatment, storage, or disposal of hazardous wastes at any place other than a federal or state-approved facility is illegal. Penalties for violation include fines and imprisonment. These prospective penalties are apparently not stringent enough, however, to eliminate the practice of illegal disposal of industrial hazardous wastes.

An EPA consultant's report in 1983 estimated that one in seven hazardous waste generators in 41 cities surveyed throughout the country had illegally disposed of its wastes at some time over a 2-year period (Savant Associates, 1983). This survey used the nominative technique where respondents were asked to nominate, in confidence, other generators who they believed were disposing illegally. The consultant did not estimate the quantity of illegal wastes, but an earlier survey for EPA by the Westat Corporation places the volume at as much as 10 percent of total wastes generated (EPA, 1981).

CHAPTER V

THE MODEL APPLIED TO INDUSTRIAL HAZARDOUS WASTES

In this chapter, we use the limited information that is available, most of which was summarized in Chapter IV, to construct quantitative models of the legal and illegal markets for industrial hazardous waste. We begin with a benchmark case based on a combination of actual data and assumed parameters for the demand, supply and external cost functions. Using a procedure for determining changes in economic welfare, we calculate the optimal liability share (λ). Then we assume different values for these parameters and calculate a series of additional values for λ. We discover that λ varies widely over the assumed range of values. The implications of these findings for theory, policy, and future research are outlined in Chapter VI.

The Benchmark Case

The model underlying the benchmark case is the same as the one depicted in Figures 3-1 to 3-3. Here we assign specific values to the parameters of the linear functions. The model can be specified as a system of 6 equations:

(1) $H(D) = H - \delta D$
(2) $C_p = A + \alpha D$
(3) $C_s = C + \alpha D$
(4) $I = E - g(dD) - \beta P_i$
(5) $P_I = \bar{P}_I$
(6) $\psi C_s = \psi \bar{C}_s$

$H(D)$ is the demand for legal disposal, C_p is the private supply of legal disposal services, C_s is the private supply of legal disposal services plus the external cost of legal disposal, I is the demand for illegal disposal, P_I is the price of illegal disposal, and ψC_s is the per unit value of the external cost of illegal disposal.

Solution of the model also requires the assignment of welfare weights to the gains or losses experienced by consumers, producers, and third parties (pollutees). In terms of the model developed in Chapter III, we need values for ω_1, ω_2, and ω_3.

Table 5-1 contains the values of the parameters assumed in the benchmark case.

TABLE 5-1
Parameters for the Benchmark Case

Parameter	Value
H	\$80
δ	- .000000143
A	\$20
α	.000000072
C	\$40
E	106.84 million tons
g	.1428
β	- 1.979 million
P_I	\$27
ψC_s	\$340
ω_1	1.0
ω_2	1.0
ω_3	1.0

The parameters in Table 5-1 are consistent with the initial price and quantity in the legal market and with assumed values for the elasticities of demand and supply. The initial price and quantity in the legal market are $40 and 280 million tons. These values are based on a 1983 Congressional Budget Office forecast of the 1990 values of the cost and volume of industrial hazardous waste disposal (CBO, 1985).

The elasticities underlying the parameters of the demand and supply functions are outlined in Table 5-2.

TABLE 5-2
Elasticities for the Benchmark Case

Elasticity (*E*)	Assumed Value
Demand, Legal Market (ED_L)	-1.00
Supply, Legal Market (ES_L)	2.00
Demand, Illegal Market (ED_I)	-1.00
Cross Price Elasticity of Demand (*CPED*)	1.00

The value for ψC_s is equivalent to Sullivan's assumption that ψC_s is 750 percent greater than C_s (Sullivan, 1986, p. 203). The value for $\underline{g}$ reflects Sullivan's assumption, based on a 1983 survey for the EPA (Savant Associates, 1983), that illegal disposal is one-seventh of the legal disposal.

Given these values, the legal market is initially in equilibrium at P = \$40 and D = 280 million tons. The illegal market is in equilibrium initially at I = 40 million tons and P_I = \$27.

The first step in the determination of the optimal λ is to compute the hypothetical equilibrium when full liability ($\lambda = 1$) is imposed on hazardous waste generators. This is the level of legal disposal where $H(D) = C_S$. Given the above parameters, this equilibrium occurs at 184 million tons. The simultaneous equilibrium in the illegal market occurs at I = 53.42 million tons.

Given these starting points, the technique for determining the optimum λ is to specify smaller or larger values for λ and then to calculate the net effect on economic welfare. Smaller and larger values are tried as long as the net effect on economic welfare is positive. When the positive effect reaches zero, the optimal λ is found.

As λ is reduced over the range between 1 and 0, the quantity of legal disposal increases and the quantity of illegal disposal decreases. Thus, economic welfare increases due to increases in consumers' and producers' surpluses in the legal market (CS_L and PS_L) and reduced external costs in the illegal market (EC_I). At the same time, however, economic welfare falls due to increased external costs in the legal market (EC_L) and the loss of consumers' surplus in the illegal market (CS_I).

At $\lambda = 0$, the net gain in CS_L plus PS_L is maximized. For $\lambda < 0$, consumers of legal waste disposal services would continue to reap gains. It would be necessary, however, to subsidize producers of legal waste disposal because the price of legal disposal would be less than the unit cost of legal disposal (C_p). The subsidy required for producers is a loss to taxpayers; in fact, the loss to taxpayers exceeds the gain to consumers of legal waste disposal services. This net loss must be added to the other losses associated with a lower λ; namely, ΔEC_L and ΔCS_I. The optimal λ can be less than zero, however, if the reduction in EC_I is large enough.

If there are no net gains from lowering λ, then it is necessary to check to see if λ should be raised above 1. With $\lambda > 1$, the quantity of legal disposal would decrease and the quantity of illegal disposal would increase. This would produce gains from smaller EC_L and larger CS_I, and losses from smaller CS_L and PS_L and larger EC_I.

Application of this procedure in the benchmark case produces an optimum λ of -1.48, as reported as Case 1 in Table 5-3. The basic data for this case are in Appendix A. In this case, the assumed value of ψC_s is so large that it pays to greatly increase the volume of legal disposal.

TABLE 5-3
ALTERNATIVE CASES

Case	ED_L	ES_L	ED_I	CPED	ψC_s	P_I	ω_3	c	Optimal λ
1	-1.0	2.0	-1.0	1.0	$340	$27	1	1	-1.48
2	-1.0	2.0	-1.0	1.0	40	27	1	1	0.88
3	-1.0	2.0	-1.0	1.0	170	27	1	1	-0.20
4	-1.0	2.0	-1.0	1.0	40	33	1	1	0.85
5	-1.0	2.0	-1.0	1.0	40	27	3	1	3.00
6	-1.0	2.0	-1.0	1.0	340	27	3	1	0.40
7	-1.0	2.0	-1.0	1.0	40	27	1	0	-0.12
8	-0.5	2.0	-1.0	1.0	40	27	1	1	0.75
9	-1.0	1.0	-1.0	1.0	40	27	1	1	0.75
10	-1.0	2.0	-0.5	1.0	40	27	1	1	1.00
11	-1.0	2.0	-1.0	0.5	40	27	1	1	0.80
12	-0.5	1.0	-0.5	0.5	340	27	1	1	-1.56
13	-0.5	1.0	-0.5	0.5	40	27	1	1	0.92
14	-0.5	1.0	-0.5	0.5	170	27	1	1	-0.02
15	-0.5	1.0	-0.5	0.5	40	33	1	1	1.00
16	-0.5	1.0	-0.5	0.5	40	27	3	1	2.70
17	-0.5	1.0	-0.5	0.5	40	27	1	0	-0.01

To implement $\lambda = -1.48$, it would be necessary to pay a large subsidy to the producers of legal waste disposal services. The gains from this subsidy, in the form of reduced EC_I, exceed the net cost of the subsidy over the range, $\lambda = 0$ to $\lambda = -1.48$, provided that there are no welfare losses from raising the money to finance the subsidy.

If there are such losses, the optimal λ would be larger (most likely, a smaller negative number) than -1.48.

Other Cases

In an ideal world, the benchmark case would be constructed upon econometric estimates of the parameters of the demand, supply, and external cost functions, and the optimal estimated λ would be close to the true λ. Unfortunately, there are insufficient data, especially for the illegal market, to support such estimates. Alternatively, there are good reasons at this stage to question some of the values assigned to these parameters in the benchmark case. Thus, we calculated the optimal λ for 16 additional cases, characterized by different sets of parameter values. The basic data for cases 2-4 and 12-15 are in Appendices A and B, respectively.

Since the optimal λ in the benchmark case depends so heavily upon ψC_s, it is necessary to look at ψC_s carefully. Sullivan chose ψC_s by citing a single estimate; namely, the cost of restoring Love Canal compared to the cost of proper legal disposal of the pollutants placed in the Canal. There are two problems with this procedure. The first problem is that Love Canal may not be representative of other sites. The second is that the cost of restoration is not necessarily a correct measure of the external cost of waste disposal.

The correct measure of the external cost of waste disposal, legal or illegal, is the amount people are willing to pay to accept pollution or to get rid of it. Either of these measures (which will differ from each other) may vary from the cost of restoration.

In general, willingness to pay is equal to the perceived risk of damage (to personal health, property, or the natural environment) times the values people place on this damage. It is entirely possible that the risks associated with hazardous waste disposal are quite small. To allow for this possibility, we construct two cases, where ψC_s = \$170 and ψC_s = \$40. As expected, the optimal λ rises in these cases. As noted in Table 5-3, $\lambda = -0.2$ when ψC_s = \$170 and $\lambda = .88$ when ψC_s = \$40.

The next parameter we changed was P_I. P_I was constructed using the following relationship: $P_I = P$ (Prosecution) × P (Conviction, if prosecuted) × Present Value of the expected fine, if convicted, where P = probability. Based on data in a 1985 study of illegal disposal (Government Accounting Office, 1985), this resulted in an estimate of \$27 for P_I.

More complete data on the determinants of P_I could produce a different value for P_I. Alternatively, a larger enforcement budget could also increase P (Prosecution) and thus increase P_I. Using elasticities estimated by Ehrlich (1975), we determined that a doubling of the enforcement budget raises P_I to \$33.

In Case 4 reported in Table 5-3, we combine this estimate of P_I = \$33 with a value of ψC_s = \$40. This produces a value for λ of 0.85, compared with $\lambda = 0.88$ when $P_I = 27$ and ψC_s = \$40. In other words, raising P_I from \$27 to \$33 (a 22 percent increase) has very little impact on λ.

In the benchmark case, every dollar gained or lost has the same weight, regardless of who gets it or gives it up. A long history of social policy suggests, however, that policy makers are not indifferent to who benefits and who pays. They are especially likely to want to attach a higher weight to the gains and losses of lower-income individuals than to the gains and losses of higher-income individuals.

We do not have enough information to distribute the costs and benefits associated with different values for λ by income class. About the only thing we can be certain of is that much of the external costs of both legal and illegal waste disposal are imposed on people who are non-white and/or poor (Commission for Racial Justice, 1987; Bullard, 1983, 1984, 1990; EPA, 1992). There is no tradition in welfare economics of weighting gains and losses for race. Some attempts have been made, however, to provide larger weights to poorer individuls (Gramlich, 1990, Chapter 7). In keeping with this tradition, we developed Case 5, in which ψC_s = \$40, and $\omega_3 = 3$. That is, we assign a weight of 3 to the changes that occur in external costs as λ falls. This weight comes from Gramlich's calculation based on the marginal tax brackets for the federal income tax (Gramlich, 1990, p. 122). Applying this weight for ω_3 (the weight on losses and gains to pollutees) increases the optimal λ to 3.0. When λ is raised above 1, pollutees in the legal market gain by virtue of a reduction in external cost. Pollutees in the illegal market, however, lose by virtue of an increase in λ. In this case, the weighted gains to pollutees in the legal market greatly exceed the weighted losses to pollutees in the illegal market.

In Case 6, a high estimate of ψC_s is combined with a large weight for ω_3. As expected, the separate effects from Cases 1 and 5 tend to offset each other. Illegal disposal occurs because the benefits to "consumers" of illegal disposal exceed the price of illegal disposal. When the price of illegal disposal, P_I, is fixed, as in our examples, and λ falls, there is an increase in consumers' surplus in the illegal market.

Up to now we have been treating this change in CS_I as a benefit from a lower λ. Some would argue that since illegal dumping is a criminal activity, gains from it should not count as part of the benefits of a lower λ (Gramlich, 1990, p. 115). Although there is a lack of unanimous agreement on this point, we allow for the possibility that the welfare of criminals does not count. This causes us to drop ΔCS_I from all of our calculations, or to assign a weight of $c = 0$ to ΔCS_I. When this is done, as in Case 7, the optimal λ is -0.12. The fall in λ from 0.88 (the relevant comparison case is Case 2) to -0.12 makes sense. When ΔCS_I counts, it acts to constrain the drop in λ; a lower λ means a loss in CS_I. When ΔCS_I does not count, this constraint is missing from the calculation and the optimal λ falls.

Table 5-3 also contains 4 cases (8-11) in which we allow for lower values (one-half of the values in Table 5-2) for the 4 elasticities on which the demand and supply functions are based. The optimal λ falls in 3 of these cases and increases in the other case. They are all relatively close, however, to the value for λ of 0.88 in Case 2.

In Case 12 in Table 5-3, the four lower elasticity values are combined with $\psi C_s = \$340$. Reducing all of the elasticities of the model lowers the optimal λ from -1.48 to -1.56. In Cases 13-17, the 4 lower elasticities are combined with the values noted in the table for ψC_s, P_I, $\omega 3$, and ΔCS_I to produce a set of optimal λs comparable to Cases 2-6 which are based on larger elasticities. With the exception of Case 16, the optimal λ increases with reductions in all of the relevant elasticities, although not by very much.

CHAPTER VI

LESSONS FOR THE LAW, ECONOMIC THEORY, ECONOMIC POLICY, AND FUTURE RESEARCH

In this chapter, we outline the primary implications of the findings of this study. The results suggest a critique of the mainstream view in both law and economics that polluters should be liable for all of the external costs that they create. They also provide some insight on changes that policy makers have recently made, or are thinking about making, in the laws and regulations governing hazardous waste management. Finally, the results of this study point to some items that should be high on the research agenda.

The Law and Economic Theory

The law relating to hazardous waste management, reviewed in Chapter II of this study, clearly places full liability for the external costs associated with hazardous wastes on the producers of hazardous wastes. This feature of the law probably largely reflects the popular view that it is "fair" to make polluters pay, but it may also reflect the view that application of full liability is consistent with efficiency in resource allocation. The "polluter pays principle" of the law is also consistent with what appears to be the prevailing view in Economics that polluters should pay for the costs they impose on others. This view underlies the proposed application of Pigouvian taxes as a means of achieving the efficient level of hazardous waste disposal.

The results of this study suggest that strict application of both the prevailing law and/or Pigouvian taxes may produce neither efficiency in resource allocation nor "fairness" in the distribution of the costs of hazardous waste management, if fairness requires that a higher weight be given to the costs imposed on lower-income victims of hazardous waste disposal. According to the model of this study, the potential inefficiency of the law and Pigouvian taxes is implied for all cases in which the optimal liability, λ, is less than 1 when the weight assigned to gains and losses of pollutees, ω_3, is equal to 1. According to the model, application of the law and Pigouvian taxes do not provide fairness or equity in the cases where λ is less than 1 when ω_3 is greater than 1.

Most of the cases examined in Chapter 5 relate to the efficiency of the law or Pigouvian taxes; namely, cases 1-4, 7-15, and 17. Cases 5, 6 and 16 in Chapter 5 relate to the fairness of the law of full liability and Pigouvian taxes. A review of the results presented in Table 5-1 shows that application of the law and Pigouvian taxes would be a source of inefficiency in resource allocation in 9 of the 14 cases examined; the exceptions are cases 10 and 15, where ω_3 is equal to 1. The relevant cases in Chapter 5 suggest that greater inefficiency in resource allocation would result from application of full liability in the face of larger values for the external costs per unit of illegal disposal, ψC_s, and the price of illegal disposal, P_I, and smaller values for the weight assigned to "criminals", c, the price elasticities of demand and supply in the legal market, ED_L and ES_L, and the cross price elasticity of demand, *CPED*. Smaller values for all of the elasticities combined tends to reduce the degree of inefficiency, although by only a small amount. The relevant cases in Chapter 5 suggest that the application of full liability in the face of larger values for ω_3 would produce greater losses in economic welfare weighted for gains and losses to low-income individuals.

Public Policy

Public policy toward hazardous wastes is constantly evolving. Currently, one of the primary goal of hazardous waste policy is to reduce the portion of hazardous waste destined for landfills. In addition, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) is up for renewal by the U.S. Congress. The debate over CERCLA is likely to center on determining the appropriate extent of cleanup of sites on the National Priorities List, the appropriate allocation of liability for cleanup costs, and the equity aspects of the siting of hazardous waste facilities. The findings of this study may suggest some lessons for policy makers as they deal with these issues.

One clear implication of the model of this study is that any policy that raises the cost of legal waste disposal is likely to induce at least some illegal waste disposal. If it does, then the optimal liability for legal waste disposal is likely to be less than the full liability prescribed by law. Alternatively, the costs of induced illegal disposal should be included in any evaluation of a policy that raises the cost of legal disposal.

The latter point is clearly relevant for the current policy bias against the use of landfills as hazardous waste sites. The Environmental Protection Agency is pushing incineration as an alternative to landfill, primarily on the grounds that it is more environmentally benign than landfill. Not only has this claim been challenged by reputable scientists (Commoner, Shapiro, and Webster, 1987), but incineration is more costly than landfill. Thus, it is reasonable to assume that the ban on landfill disposal of hazardous waste induces an increase in illegal disposal. If it does, a full accounting for the costs of the ban would include the costs associated with the illegal disposal of hazardous waste.

Alternatively, suppose that the authorities have already decided on incineration as a favored technology. Then, the model of this study is directly transferable to the case of incineration. In such an application, the objective would be to determine the optimal share of the external costs of (legal) incineration for which the incinerator is liable. Given the inducement for illegal disposal stemming from the high cost of incineration, the optimal share is likely to be less than 1. Moreover, according to Costner and Thornton (1990, p.3), economically disadvantaged communities are especially likely to be the hosts for incinerators that burn hazardous waste. This suggests that application of appropriate weights to the gains and losses of low-income individuals would increase the likelihood that the optimal liability for the external costs of incineration would be less than 1.

The results of this study also suggest that authorities will have to be careful when devising policies to reduce the impact of hazardous waste disposal on communities composed predominantly of low-income and/or non-white families. If the action chosen, for example, is a ban on the siting of facilities in such communities, this will increase the cost of hazardous waste disposal and increase the risk of illegal disposal adversely affecting these communities. In this case, a better alternative to a ban may be the toleration of some siting of facilities in predominantly low-income and/or non-white areas.

It was noted above that there is currently a policy debate also regarding the appropriate level or extent of cleanup at hazardous waste sites. There is a possibility that policymakers will decide to require that affected sites be returned to their natural state. This action will tend to produce relatively high values for the cost of cleanup. Some may interpret this as a high value for ψC_s, and argue that it suggests a relatively low value for the optimal liability share. This is not the appropriate response, however, because the optimal liability share should be based on an estimate of ψC_s that reflects peoples' willingness to pay for site cleanup, and that may be quite different from the cost imposed by policymakers.

Future Research

Ultimately, the usefulness of this model in policy debates rests on subsequent empirical estimation of the demand and supply functions for hazardous waste disposal, the external costs associated with hazardous waste disposal, and the approppriate welfare weights for the gains and losses of affected parties. The results of this study indicate that the optimal liability share is most sensitive to the values attached to external costs and the welfare weights. Additional research should probably begin with these parameters.

The optimal liability share seems to be relatively insensitive to the basic elasticities of the model. Perhaps this is because elasticities were used in a restricted way; namely, as a means of calculating the slopes (and in the case of the CPED, the shift parameter) of functions that were assumed to be linear. Econometric estimation of the demand and supply functions may indicate that the relevant functions are not linear,and that the optimal liability share is more sensitive to the relevant elasticities.

The optimal liability share also seems to be quite insensitive to the value of the enforcement budget that affects the price of illegal disposal. There is perhaps enough policy interest in direct means of reducing illegal disposal that further research on this aspect of the problem is needed. Policymakers may want to know, for example, if it is cheaper to subsidize legal disposal as a means of reducing illegal disposal than it is to spend more money on law enforcement for that purpose.

Finally, there are 4 costs that are relevant to the determination of the optimal liability share that have not been explicitly incorporated in the model of this study that would seem to warrant attention by future researchers. First, it has been noted previously in this study that a lower value for the optimal liability share may require a subsidy of waste generators by taxpayers. If so, then the solution to the model requires the inclusion of the welfare cost (excess burden) of taxation. Inclusion of this cost would increase the optimal liability share. Lowering the optimal liability share may create cost-savings in 3 areas, however: litigation, enforcement, and compliance. If it does, these cost-savings would tend to decrease the optimal liability share. Whether they would be large enough to offset the increased welfare cost of taxation is a worthy subject for future research.

REFERENCES

1. Pub. L. 91-604, Dec. 31, 1970, 80 Stat. 1676.
2. Pub. L. 92-500, Oct. 18, 1972, 86 Stat. 816
3. Pub. L. 93-523, Dec. 16, 1974, 88 Stat. 1660.
4. Pub. L. 94-469, Oct. 11, 1976, 90 Stat. 2003.
5. Pub. L. 94-580, Oct. 21, 1976, 90 Stat. 2795.
6. 40 C.F.R. Part 261.
7. 40 C.F.R. Part 262.
8. 40 C.F.R. Part 263.
9. 40 C.F.R. Part 265.
10. 42 U.S.C. Section 6925.
11. 42 U.S.C. Section 6924.
12. 42 U.S.C. Section 6928(h).
13. 42 U.S.C. Section 6924(u) and (v).
14. 42 U.S.C. Section 6922(a).
15. 42 U.S.C. Section 6928.
16. Pub. L. 96-510, Dec. 11, 1980, 94 Stat. 2767.
17. Pub. L. 99-499, Oct. 17, 1986, 100 Stat. 1613.
18. 40 C.F.R. Part 300.
19. 42 U.S.C. Section 9604(c)(1).
20. 42 U.S.C. Section 9604(c)(4).
21. 42 U.S.C. Section 9621.

22. 42 U.S.C. Section 9662(e).

23. 42 U.S.C. Section 9607.

24. *State of New York v. Shore Reality Corporation*, 759 F2d 1032 (2nd Cir. 1985); *United States v. Conservation Chemical Company*, 589 F. Supp. 59 (W.D. MO 1984).

25. *United States v. A and F Materials Company*, 578 F. Supp. 1249 (S.D. Ill 1984); *United States v. Chemical Dyne*, 572 F. Supp. 802 (S.D. Ohio 1983).

26. 42 U.S.C. Section 122(e)(1).

27. 42 U.S.C. Section 9622(e)(3).

28. 42 U.S.C. Section 122(g).

29. *Smith Land and Improvement Corporation v. Celotex Corporation*, 851 F. 2d. 86, (3rd Cir., 1988).

30. 42 U.S.C. Section 6903.

SELECTED BIBLIOGRAPHY

Baumol, William J. and Wallace E. Oates. "The Use of Standards and Prices of Protection of the Environment." *Swedish Journal of Economics*, March 1971, 73: 42-54.

Braulke, Michael and Aalfred Endres. "On the Economics of Effluent Charges." *Canadian Journal of Economics*, November 1985, 18: 891-897.

Buchanan, James M. and Gordon Tullock. "Polluters' Profits and Political Response: Direct Controls Versus Taxes." *American Economic Review*, March 1975, 65: 139-147.

Bullard, Robert D. "Solid Waste Sites and the Black Houston Community." *Sociological Inquiry*, Spring 1983, 52: 273-288.

__________. "Endangered Environs: The Price of Unplanned Growth in Boomtown Houston." *California Sociologist*, Summer 1984, 7: 85-101.

__________. *Dumping in Dixie: Race, Class, and Environmental Quality*. Boulder: Westview Press, 1990.

__________ and Beverly H. Wright. "Dumping Grounds in a Sunbelt City." *Urban Resources*, Winter 1985, 2: 37-39.

Commission for Racial Justice, United Church of Christ. *Toxic Wastes and Race in the United States: A National Report on the Racial and Socioeconomic Characteristics of Communities with Hazardous Waste Sites*. New York: United Church of Christ, 1987.

Commoner, Barry, Karen Shapiro and Thomas Webster. "The Origin and Health Risks of PCDD and PCDF." *Waste Management and Research*, 1987,5: 327-346.

Congressional Budget Office. *Hazardous Waste Management: Recent Changes and Policy Alternatives*. Washington, D.C.: U.S. Government Printing Office, 1985.

Costner, Pat and Joe Thornton. *Playing With Fire: Hazardous Waste Incineration*. Washington, D.C.: Greenpeace, 1990.

Dechert, W. Davis and James L. Smith. "Environmental Liability and Economic Incentives for Hazardous Waste Management." *Houston Law Review*, 1988, 25: 935-942.

De Meza, David. "The Efficacy of Effluent Charges." *Canadian Journal of Economics*, February 1988, 88: 182-186.

Dewees, Donald N. "Instrument Choice in Environmental Policy." *Economic Inquiry*, January 1983, 21: 53-71.

Ehrlich, Isaac. "Participation in Illegitimate Activities: An Economic Analysis." In *Essays in Economics of Crime and Punishment*. G.S. Becker and W.M. Landes, eds. New York: National Bureau of Economic Research, 1974.

Fox, Merritt B. "Corporate Successor Under Strict Liability: A General Economic Theory and the Case of CERCLA.: *Wake Forest Law Review*, 1991, 26: 182-216.

Gramlich, Edward M. *A Guide to Benefit-Cost Analysis*, 2nd Ed. Englewood Cliffs, N.J.: Prentice-Hall, 1990.

Helfand, Gloria E. "Standards Versus Standards: The Effects of Different Pollution Restrictions." *American Economic Review*, June 1991, 81: 622-637.

Hochman, Eithan and David Zilberman. "Examination of Environmental Policies Using Production and Pollution Microparameter Distribution." *Econometrica*, July 1978, 46: 739-760.

Johansen, Leif. *Production Functions: An Integration of Micro and Macro, Short Run and long Run Aspects*. Amsterdam: North-Holland Publishing Company, 1972.

Knease, Allen V. and Charles Schultze. *Pollution, Prices and Public Policy*. Washington, D.C.: Brookings, 1975.

Kolstad, Charles D., Thomas S. Ulan, and Gary V. Johnson. "Ex Post Liability for Harm Versus Ex Ante Safety Regulation: Substitutes or Complements?" *American Economic Review*, June 1990, 80: 880-901.

Lands, William M. and Richard A. Posner. "Joint and Multiple Tort-Feasers: An Economic Analysis. *Journal of Legal Studies*, June 1980, 9: 517-555.

Opaluch, James J. "The Use of Liability Rules in Controlling Hazardous Waste Accidents: Theory and Practice." *Northeastern Journal of Agricultural Economics and Resource Economics*, October 1984, 13: 210-217.

Pigou, Arthur C. *The Economics of Welfare*. 4th Ed. London: Macmillan, 1932.

Savant Associates, Inc. *Experiences of Hazardous Waste Generators with EPA's Phase I RCRA C Program*. Washington, D.C.: Environmental Protection Agency, 1983.

Sullivan, Arthur M. "Liability Rules for Toxics Clean-Up." *Journal of Urban Economics*, September 1986, 20: 191-204.

_________. "Policy Options for Toxics Disposal: Laissez-Faire, Subsidization, Enforcement. *Journal of Environmental Economics and Management*, June 1987, 14: 58-71.

Tietenberg, Thomas H. "Indivisible Toxic Torts: The Economics of Joint and Seperal Liability." *Land Economics*, November 1989, 65: 305-319.

Thomas, Vinod. "Welfare Cost of Pollution Control." *Journal of Environmental Economics and Management*, June 1980, 7: 90-102.

Tort Policy Working Group, *Report of the Policy Working Group on the Causes, Extent and Policy Implications of the Current Crisis in Insurance Avoidability and Affordability*. Washington, D.C.: Environmental Protection Agenncy, 1986.

U.S. Environmental Protection Agency. *The Hazardous Waste System*. Washington, D.C.: U.S. EPA, 1987.

U.S. Environmental Protection Agency. *Environmental Equity: Reducing Risk for All Communities*. Washington, D.C.: U.S. EPA, 1992.

U.S. General Accounting Office. *Siting of Hazardous Waste Landfills and Their Correlation With Racial and Economic Status of Surrounding Communities*, Washington, D.C.: U.S. Government Printing Office, 1983.

_________. *Illegal Disposal of Hazardous Waste: Difficult to Detect or Deter*. Washington, D.C.: GAO, 1985.

Westat, Inc. *National Survey of Hazardous Waste Generators and Treatment, Storage and Disposal Facilities Regulated Under RCRA in 1981*. Washingotn, D.C.: EPA, 1984.

White, Michelle J. and Donald Wittman. "Long-Run Versus Short-Run Remedies for Spatial Externalities: Liability Rules, Pollution Taxes and Zoning." In *Essays on the Law and Economics of Local Government*. Daniel Rubinffeld, Ed. Washington, D.C.: Urban Institute, 1979.

Willett, Keith D. "Efficiency - Distributional Trade Offs in the Taxation of Environmental Pollution." Unpublished manuscript, Oklahoma State University, January 1993.

APPENDIX A
BASIC DATA FOR CASES 1-4
($ million)

λ	ΔCS_L + ΔPS_L	ΔEC_L ($\omega_3=1$)	ΔCS_I ($P_I=27$)	ΔCS_I ($P_I=33$)	ΔEC_I ($\psi C_s=40$)	ΔEC_I ($\psi C_s=340$)
.9	382	392	36	28	54	456
.8	401	430	35	27	54	456
.7	420	468	33	26	54	456
.6	439	506	32	24	54	456
.5	458	544	31	23	54	456
.4	477	582	29	21	54	456
.3	496	620	28	20	54	456
.2	515	658	27	19	54	456
.1	534	696	25	17	54	456
0	553	734	24	16	54	456
-.1	-10	190	22	14	54	456
-.2	-29	190	21	13	54	456
-.3	-48	190	20	12	54	456
⋮	⋮	⋮	⋮	⋮	⋮	⋮
-1.3	-238	190	6	0	54	456
-1.4	-257	190	5	0	54	456
-1.5	-276	190	4	0	54	456

APPENDIX B

BASIC DATA FOR CASES 12-15

($ million)

λ	$\Delta CS_L + \Delta PS_L$	ΔEC_L ($\omega_3=1$)	ΔCS_I ($P_I=27$)	ΔCS_I ($P_I=33$)	ΔEC_I ($\psi C_s=40$)	ΔEC_I ($\psi C_s=340$)
.9	469	474	22	19	18	162
.8	478	484	22	19	18	162
.7	487	494	21	18	18	162
.6	496	504	21	18	18	162
.5	505	514	20	17	18	162
.4	514	524	20	17	18	162
.3	523	534	19	16	18	162
.2	532	544	19	16	18	162
.1	541	554	18	15	18	162
0	550	564	18	15	18	162
-.1	-5	94	17	14	18	162
-.2	-14	94	17	14	18	162
-.3	-23	94	16	13	18	162
-.4	-32	94	16	13	18	162
-.5	-41	94	15	12	18	162
-.6	-50	94	15	12	18	162

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