**Strict Liability as a Deterrent
in Toxic Waste Management:
Empirical Evidence from Accident and Spill Data**

by

Anna Alberini
Economics Department
University of Colorado, Boulder
Boulder, CO

and

David H. Austin
Quality of the Environment Division
Resources for the Future
Washington, DC

August, 1997

Abstract

This paper explores the issue of whether strict liability imposed on polluters has served to reduce uncontrolled releases of toxics into the environment. To answer this question, we exploit the variation in state hazardous waste site laws across states and over time. We use data on accidents and spills involving hazardous substances and fit regressions relating the frequency of spills of selected chemicals used in manufacturing to the type of liability in force in a state and state manufacturing activity. Results vary with the chemical being analyzed. For some chemicals, the presence of strict liability does not provide any additional explanatory power for the number of spills beyond what is achieved by the number of establishments and the sectoral composition of manufacturing. For other families of chemicals, we find that spills are more numerous in states that impose strict liability. Further investigation suggests that (i) for some of these chemicals, this could be due to unobserved state characteristics influencing spills, which may have acted to reduce the incentives of liability, and that (ii) small firms are responsible for a disproportionate number of spills, regardless of the liability structure. An alternative explanation, supported by the results of a separate regressions for two liability regimes, is that only *under strict liability* are small firms responsible for a disproportionate number of spills.

Strict Liability as a Deterrent in Toxic Waste Management: Empirical Evidence from Accident and Spill Data.

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1. Introduction

The purpose of this paper is to explore the issue of whether strict liability imposed on polluters has served to reduce uncontrolled releases of toxics into the environment. Because it imposes pollution damages upon the polluter, strict liability should create additional incentives for firms to handle hazardous substances more carefully, thus reducing the future likelihood of such uncontrolled releases.

Provisions making polluters liable for the damages caused by their polluting activities have, in fact, been incorporated into a number of federal and state environmental laws passed over the last two decades, such as CERCLA (1980; re-authorized in 1986 and extended in 1991[1]), the hazardous waste cleanup laws of many states, and the Offshore Continental Shelf Act (1974), which deals with damages from off-shore spills occurring during drilling operations.

It has been argued that liability law is an important and promising policy tool for dealing with pollution problems (Tietenberg, 1989). Economic theory, however, is ambivalent about its effects. Firms with relatively limited assets may be sheltered from the economic incentives created by strict liability (Shavell, 1984; Tietenberg, 1989). Beard (1990) and

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[1] The Comprehensive Environmental Response, Compensation and Liability Act, commonly known as Superfund, instructs the U.S. Environmental Protection Agency to identify and list hazardous waste sites that pose a threat to human health and the environment, track down potentially responsible parties and force them

Larson (1996) find that the effect of imposing strict liability remains, at best, uncertain. They dispel the notion that under strict liability the level of care taken by a firm to prevent accidental releases is always increasing in firm wealth, and conclude that large, wealthy firms may or may not be safer than smaller ones.

Firms may even select their asset level or corporate financial structure to minimize payment of damages in the event of an accident (Pitchford, 1995). Ringleb and Wiggins (1990) provide evidence that imposition of strict liability may have in fact encouraged wealthier firms to spin off into, or subcontract risky operations to, smaller, judgment-proof companies in hopes of avoiding liability. Finally, the incentives created by liability can be altered by the availability and cost of pollution insurance.

In light of the many possible effects of imposing liability on polluters, it is rather surprising that so little empirical work has been done to date to examine firms' actual responses to environmental liability law. Opaluch and Grigalunas (1984) present evidence that bids for tracts on the Outer Continental Shelf *do* reflect the environmental risks perceived by firms under the Offshore Continental Shelf Act, but we are not aware of any empirical studies examining the role of liability as a deterrent to uncontrolled releases of toxics into the environment.

In this paper, we set out to explore this issue, focusing specifically on firm liability for the cost of remediation at hazardous waste sites. Under the Federal Superfund law, certain parties – including waste generators and transporters, and operators of waste sites – are held responsible for any cleanup costs at high-risk toxic waste sites, without requiring proof they

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to clean up (or to reimburse EPA for a cleanup already initiated by the agency). The EPA has generally interpreted the law to apply to closed and abandoned hazardous waste sites.

acted negligently or with intent (Fogleman, 1992).[2] In addition, many states have established their own cleanup programs, with authorities and capabilities similar to those of the federal Superfund program. These state cleanup programs were authorized within a few years after the passage of the federal Superfund, in order to address the numerous sites which are not included on the National Priority List (NPL), and so do not qualify for federally financed remediation (Barnett, 1994).[3] Their specific provisions, including the imposition of strict liability, vary across states, and many have evolved considerably since the program's inception. These differences, across states and over time, provide us with a natural experiment for assessing strict liability's effects on the handling of toxics.

We use data on accidents and spills involving hazardous substances to establish whether their frequency of occurrence has been systematically affected by the introduction of strict liability. The data come from a comprehensive database of events reported to the US EPA under their Emergency Response Notification System (ERNS). Because ERNS begins in 1987, we are unable to establish whether the passage of the federal Superfund law has affected the occurrence of accidental releases. Instead, we examine whether the strict liability feature of state cleanup programs has had any *additional* influence on the number of accidental events, above and beyond that of the federal Superfund. In particular, we wish to see whether the effect of strict liability on firms' handling of toxic materials has been uniformly to reduce the incidence of toxic spills, or whether its effect is dependent on firm size and other factors.

[2] The courts have interpreted Superfund as imposing joint and several liability, which holds all potentially responsible parties liable for the entire amount of the cleanup when it is not possible to determine their individual contributions.

[3] The state mini-superfund programs also contain provisions for the funding of the state's share of the cost of cleanup at NPL sites. Such share is mandated by CERCLA.

To study this relationship, we estimate regressions relating the frequency of spills of selected chemicals used in manufacturing to the type of liability in force in a state. We control for the extent of manufacturing activity in the state, and include in the regression other program features that might alter firms' expected outlays in the event of an accident, and thus affect firms' incentives to take care.

Results vary with the chemical being analyzed. For some chemicals, such as halogenated solvents, the presence of strict liability does not provide any additional explanatory power for the number of spills beyond what is achieved by the number of establishments and the sectoral composition of manufacturing. For other families of chemicals (acids, ammonia and chlorine), spills appear to be more numerous where strict liability is imposed, even after we control for the extent and type of manufacturing. We present several alternative models and tests to shed light on this initial finding, looking for evidence about the effects of firm size.

The paper is organized as follows: Section 2 presents theoretical considerations. Section 3 describes our data on accidental releases of toxics. Section 4 discusses the state mini-superfund programs and section 5 discusses the role of pollution insurance. The econometric model, the variables and the regression strategy are presented in Section 6. Section 7 presents the results and Section 8 concludes.

2. Theoretical considerations

To provide a framework for our empirical work, this section we examine models of firms' optimal levels of care against uncontrolled releases of pollutants into the environment.

Shavell (1984) considers a firm that, at some cost *x,* can reduce its likelihood of an accident. When an accident occurs, damages are equal to $D, which is fixed for a given firm, but varies across firms. The regulator knows only the distribution of D over the firms, but not the firm-specific level of D. Shavell shows that -- if the harm caused by some parties can exceed their assets, or if some parties can escape legal judgement -- the level of care taken by a firm under strict liability is less than the socially optimal level. Under strict liability the level of care, and hence the likelihood of an accident, should, therefore, depend on the firm's total potential liability, D;[4] on its wealth, W; and on the probability of a suit, p. The firm's level of care increases with the size of the potential damages D it faces, but only so long as D is less than the wealth of the firm.[5]

Variants of this model, such as those developed by Beard (1990) and Larson (1996), do not necessarily support this hypothesis, dispelling the notion that under strict liability the level of care taken by a firm to prevent accidental releases is always increasing in firm wealth: Large, wealthy firms may or may not be safer than smaller ones.[6] Taken together, the Beard and Larson models suggest that whether strict liability increases or decreases the likelihood of

[4] D includes, in the case of remediation at hazardous waste sites, cleanup costs, compensation to victims, and punitive damages (if prescribed by law).

[5] Shavell goes on to compare ex post liability with regulation, showing that liability can be superior to regulation when the likelihood of a suit is high, firms' assets are large relative to damages, or there is heterogeneity across firms in the size of potential damages they face. Joint use of regulation and liability can induce levels of care better than those chosen by firms under regulation or liability regimes alone.

[6] Beard allows the size of the damages from an accident to be random. While the probability of an accident is influenced by a firm's level of care, in this model the distribution of the size of the damages is not. As in Shavell's model, if the damages exceed the assets of the firms, disbursements are virtually "truncated" by bankruptcy. This makes the private benefits of care lower than the social benefits, and the private costs of care lower than the social costs. In Beard's model, firms subject to strict liability may *either* over- or under-invest in care relative to the socially optimally level, depending on the distribution of accident size, and wealthy firms may *not* necessarily invest in more care than smaller firms. Larson considers firms facing uncertainty about their profits in addition to uncertainty about accidental releases. Firms choose between allocating resources to production involving toxics and to riskless investments. Firms' level of care is shown to be increasing in wealth only for firms operating in "extremely hazardous" sectors (where an accident would always put the firm out of business).

accidents relative to the social optimum, given firm assets, remains an empirical issue, and that no prior expectations can be formed on the direction of the effects of W and D on the likelihood of accidental events.

When strict liability is compared with negligence-based liability, the difference in the level of care taken by a firm under the two alternative regimes may depend on W, D, p, and on $\hat{x}$, the negligence standard established by the courts (Tietenberg, 1989). Formally, the difference in accident probabilities between strict liability and a negligence-based liability regime can be expressed as:

(1) $$(P_N - P_S) = f(D, W, \hat{x}, p; I)$$

where P_I denotes the probability of an accidental release of toxics under regime I, I $\in$ {N(egligence), S(trict)}. Equation (1) informs our empirical analyses by suggesting that in addition to I, we must control for potential liability, firm wealth, court-established standards of negligence, and the probability of environmental law suit.

None of the models reviewed here explicitly considers the possibility that a firm might purchase insurance against accidental releases of toxics. Firms may become insensitive to the imposition of strict liability to the extent they can purchase pollution insurance, but the insurance industry effectively rations insurance, requiring firms to provide proof of care against accidents, and making coverage very expensive.[7]

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[7] Some observers have indeed argued in favor of requiring hazardous waste generators and haulers, and operators of commercial hazardous waste facilities, to purchase insurance against accidental releases of pollutants into the environment, while maintaining either negligence-based or strict liability. The idea behind this proposal is that the insurance industry would require appropriate safety measures on the part of potential polluters. Whether insurance is mandatory or optional, insurance companies are likely to respond by rationing the provision of insurance (Hanley, Shogren and White, 1997). Until the 1970s, comprehensive general liability (CGL) policies covered the risk of environmental liabilities, provided that releases of pollutants were sudden and accidental. Since 1986, however, CGL policies contain absolute pollution exclusions (although in 11 states—AL, CO, GA, IL, IN, NJ, OR, SC, WA, WV, WI—this exclusion has successfully been challenged).

In this paper, we explore the empirical issue of how strict liability has affected the level of care taken by firms to prevent unintended releases of pollutants into the environment. We examine the ultimate outcome of care, focusing on sudden and accidental releases that occurred over a relatively recent time period. Datasets documenting individual spill events are publicly available, but in most cases do not contain information sufficient to identify the parties responsible for the spill. Hence, we aggregate the spill counts by state and year.

If economic theory does not offer unambiguous predictions for how *individual* firms adjust their level of care—and hence the likelihood of toxic spills—to the liability structure, matters become even more complicated when one examines total spills per state per year. Total spills may depend on individual firm propensities to spill, the distribution of damages for firms of given size, the distribution of firm sizes, the state's liability structure, the negligence standards likely to be established by state courts, the availability and cost of pollution insurance, and the likelihood of detection and prosecution in the event of a chemical release. We use state-level variables proxying for all of these factors, and for the degree of heterogeneity among firms in the state, as predictors of the number of spills.

3. The spill and accident data.

Our spill and accident figures come from EPA's Emergency Response Notification System (ERNS) database.[8] For each spill or release, the ERNS database reports the date and

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Insurers write "specialized environmental impairment liability policies", but these are hard to obtain and very costly (King, 1988).

[8] Reporting requirements are spelled out in Superfund (CERCLA), the Emergency Planning and Community Right-to-Know Act (EPCRA) of 1986, the Hazardous Material Transportation Act (HMTA) of 1974, and the Clean Water Act. Reporting criteria vary, depending on the federal statute. CERCLA, Section 103, requires that any release of a CERCLA hazardous substance meeting or exceeding the reportable quantity prescribed in 40 CFR 302.4 be reported to the National Response Center. Several CERCLA toxic substances are also

place where each discharge occurred; identifies the nature of the substance spilled, the statute under which the release was reported, and the medium into which the substance was released (air, etc.); and specifies whether the accident occurred during transportation or within a facility. It also attempts to identify the cause of the accident and provide a rough description of the circumstances surrounding the accident. Unfortunately, cause and description information are incomplete or missing for most spills.

Figures for the number of people injured, the number of fatalities, the number of people evacuated from a facility, and the estimated damage to property (in dollars) are also provided. Finally, the ERNS data indicate whether the party responsible is a private citizen, a firm, or a government agency. In most cases, however, firm names, addresses and Dun & Bradstreet identification numbers are not available.

We were initially interested in estimating joint models of the *quantity* of chemicals released and the number of releases. We were concerned that strict liability would have affected the severity of spills, as well as their number. We found, however, that for many spills the quantity released data are missing or set to zero for lack of better information, making total quantities systematically under-reported. Accordingly, in this paper we analyze the determinants of the *number* of spills per year in each state, from the beginning of 1987 to the end of 1995.

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simultaneously defined as RCRA hazardous wastes, Clean Air Act hazardous air pollutants, and “imminently hazardous” substances addressed by the Toxic Substances Control Act. EPCRA requires that the release of a reportable quantity of an EPCRA extremely hazardous substance or a CERCLA hazardous substance (one pound or more, unless otherwise specified by regulation) resulting in exposure of people outside the boundary of the facility where the release occurs be reported to the State and local authorities. HMTA requires that the release of a DOT hazardous material during transportation be reported to the National Response Center under certain circumstances, such as death, injury, significant property damage, evacuation, highway closure, etc. Finally, the Clean Water Act requires that the release of oil be reported to the National Response Center if the release: (1) violates applicable quality standards; (2) causes a film, sheen or discoloration of the water or

Since our data are aggregated to the number of spills and accidents per state per year, we need a way of controlling for differing patterns in the way various chemicals are used in manufacturing, which may influence the seriousness of the damages from the spills. We control for differences in how each chemical is used by organizing our analyses along more or less narrow chemical divisions. This approach also has the advantage of controlling for differences in the ways such substances may be regulated, and in ERNS reporting requirements.

Specifically, we focus on spills involving selected substances or groups of relatively similar, highly toxic, CERCLA-regulated substances used in manufacturing: (1) acids; (2) chlorine and chlorine dioxide; (3) anhydrous ammonia; (4) four halogenated solvents: methylene chloride (METH), perchloroethylene (PERC), trichloroethylene (TCE), and 1,1,1- or 1,1,2-trichloroethane (TCA); and (5) a broader group of halogenated solvents that adds methyl-ethyl ketone, chloroform, and carbon tetrachloride to the four solvents already mentioned. (See Appendix A for information about these chemicals.)

Most of the spill events here analyzed involved relatively low-level releases, rarely resulted in deaths and infrequently required remediation. Out of the 12,662 ERNS-reported accidents involving releases of acids between 1987 and 1995, more than 22 percent involved sulfuric acid, and over 14 percent involved hydrochloric acid. A significant fraction of these spills occurred in California, which between 1987 and 1995 had 2,354 spills reported to ERNS, followed by Texas (2,027), Louisiana (720), and Pennsylvania and Illinois (453 each), as shown in Figure 1. About 51.4 percent of these spills are classified as primarily affecting land, another 25.5 percent affected air, 15.4 percent water; 3.4 percent of the spills were contained within a firm's facility, and 1.3 percent affected groundwater. Most of the spills occurred at a

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adjoining shoreline; or (3) causes a sludge or an emulsion to be deposited beneath the surface of the water or firm's facility (70%),[9] with highway and railroad spills accounting for another approximately 11.6 and 10.7 percent of the spills, respectively.

Acid spills were by far the most common type of accident in the ERNS data among the chemical families we examine. By contrast, over the nine years between 1987 and 1995 there were 3,412 releases of chlorine or chlorine dioxide and 5,995 accidental releases of anhydrous ammonia. Over three-quarters of these releases occurred into air. We counted more than 2,000 accidents involving METH, PERC, TCE, and TCA (air releases slightly outnumbering spills on land, 43% to 38%, with the remainder distributed 12% in water, 2.8% in groundwater, and 1.6% contained within the facility). Even more so than with acid spills, most of these releases (over eight-five percent) occurred at a fixed facility, as opposed to during transport. The remainder of the releases were about equally distributed among highway and railroad spills.

For all of the families of chemicals considered here, the geographic distribution of the spills is qualitatively very similar to that displayed in Figure 1 for acids, suggesting that accidental releases tend to be most common in large states with strong manufacturing economies, and especially in states with a significant amount of activity in the chemical sectors. The number of spills should, therefore, be related to the number of firms and to production levels in the manufacturing and chemical-intensive sectors of each state. Because chemical transport is regulated by a complex web of federal, state and local regulations (Wentz, 1989), our analyses are limited to the spills and accidents that occur at a fixed facility, such as a manufacturing plant or a storage facility.

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upon the adjoining shoreline.

[9] Note the difference between a spill at a firm's facility (70 percent of all spills), and one that was successfully contained within the facility (without spilling on the ground or into air or water; only 3.4 percent of all spills).

4. State mini-superfund programs.

Since the early 1980s, many states have enacted laws and developed programs similar to the federal Superfund program, providing for emergency response actions and long-term remediation at hazardous waste sites. These statutes often establish a financing mechanism to pay for initial feasibility studies and remediation activities, spell out the conditions under which monies from such funds are to be used, and contain provisions conferring authority to force responsible parties to conduct feasibility studies and cleanups, and/or pay for them (EPA, 1989, 1990, 1991; ELI, 1993, 1995).

By 1989, thirty-nine states had created such funding and enforcement authorities. This number had climbed to 45 by 1995, as shown in Figure 2. The five states without separate mini-superfund programs addressed hazardous waste issues using other regulations.

One important difference between the Federal Superfund program and many state mini-superfund programs lies in the liability standards imposed on the responsible parties: Liability under the federal Superfund is strict, joint and several, but this is not necessarily the case for many of the state programs. As of 1987, only twenty-seven states had instituted strict liability; by 1995 this number had climbed to forty.[10]

The state mini-superfund programs may enable states to initiate cleanup when the responsible parties are uncooperative, and to seek to recover cleanup costs from them. State mini-superfund laws may also include provisions allowing private citizens, as opposed to government agencies, to file civil actions requiring that the responsible party prevent further damage or take corrective action if citizens have been adversely affected. In some states (15 in

[10] Strict liability is often, but not always, paired with joint-and-several liability. In 1987, 8 states had strict, but not joint-and-several, liability and 19 had both. By 1995, the number of states with strict, but not joint-and-several, liability, was 6, while states with both strict and joint-and-several liability numbered to 34.

1995) responsible parties must compensate those who are affected by the release of the toxic substances. Compensation is usually limited to paying for alternative drinking water supplies or for temporary relocation.

5. The Role of Pollution Insurance

The ability of private firms to insure themselves against their potential environmental liabilities would, under the right conditions, mute the incentives of liability we wish to observe. In particular, were insurers required to sell environmental insurance to all who demand it, and were they unable to monitor firms' level of care, the only incentives firms would have to take efficient levels of care would be reputational and moral.

The actual situation with environmental insurance differs sufficiently from this extreme scenario that firms' incentives to avoid environmental liabilities remain robust. Perhaps the central issue governing firms' incentives is the ability of insurers to exclude pollution liability claims from their commercial general liability (CGL) policies. Pre-1986 CGL policies did exclude pollution coverage except for "sudden and accidental" spills. After 1986, however, firms had to purchase all of their pollution coverage separately. The insurance industry, concerned about the potentially huge environmental liabilities, imposes rigorous documentary requirements on their policy-holders (Gastel, 1998).

Still, pollution insurance can be financially beyond reach for some firms and some types of activities. Unavailability of insurance for hazardous waste treatment, storage and disposal facilities (TSDFs) has been particularly hard on landfills and surface impoundments, which are required by the Resource Conservation and Recovery Act to carry insurance for non-sudden accidental releases (GAO, 1987). Insurance for generators of hazardous wastes and toxics also has been hard to find, and insurance policies and pollution exclusions have been an important source of contention (and transaction costs) between the insured, the insurance companies and their re-insurers (Acton and Dixon, 1992).

On the other hand, the 1986 absolute pollution exclusion has not gone unchallenged. Numerous states (see footnote 7) have failed to enforce the pollution exclusion. The temporal language of “sudden and accidental” has been interpreted broadly in such states, as with New Jersey’s ruling that “insurers are liable for cleanup if the pollution discharge was accidental and unintended” (Gastel, 1998). California’s Supreme Court has affirmed a ruling allowing firms operating there to draw from their general liability insurance policies for damages occuring from the time the pollution began until the firm’s liability is discovered (Gastel, 1998). This court has also placed the burden of proof on insurers to demonstrate that a claim falls outside the coverage of the policy. A New York appeals court, on the other hand, arguing that the pollution exclusion would end “subsidized pollution,” has upheld the apparent intent of the exclusion.[11]

Ideally, then, our analysis would control for states’ differing interpretations of the pollution exclusion, as well as data on total environmental insurance coverage by state and year, and on insurers’ safety requirements imposed upon the prospective insured. However, we were unable to find this information.

A lack of data about the availability and extent of pollution insurance forced the Government Accounting Office (GAO) to survey insurance providers in an effort to ascertain how hazardous waste legislation had affected the availability of insurance and claims paid out to the insured (1987). The survey revealed that in 1985 specialized pollution insurance made up only 0.5% of total premia paid for property/casualty insurance, and that the median claim paid out to the insured was approximately $5000.

Insurers interviewed as part of the GAO study did assert that “CERCLA’s standards of liability not only have reduced the availability of pollution insurance, but also have affected the standard of care owed by generators, transporters, and owners/operators of TSDFs.” They further maintained that “liability standards undermine these parties’ incentives to exercise due care to prevent pollution because the standard of care is not related to the potential for liability.” According to the GAO report, however, this view contrasts sharply with the opinion expressed by other parties, such as an official of the largest commercial waste disposal company who thought that “the standards of liability have in fact increased the standard of care taken by the industry.”

6. Regression models.

To check whether a state’s liability structure influences the frequency of accidents, we exploit differences in the provisions of the various state mini-superfund programs. In this paper, we focus on spills occurring at fixed facilities, and separately analyze each chemical family, explaining *numbers* of spills. For the two chemical families with an abundance of spills per year – acids and ammonia – we use linear regression models. For the other families with fewer spills, we use Poisson models.

For spills of acids and ammonia, we estimate the regression equations:

(2) $$\log(y_{it} + 1) = x_{it}\beta + \varepsilon_{it}$$

[11] Technician Electronics Corp. *v.* American Home Assurance Co., *et al.,* No. 2580. Reference provided by Gastel (1998).

where y is the number of accidental releases of these chemicals in state i in year t. The vector x contains factors that are thought to be predictors of the number of spills and that proxy for the elements in equation (1). β is a vector of parameters and ε is an i.i.d. error term. There are 51 "states" in the analysis, including the District of Columbia; the year ranges between 1987 and 1995.

For the chlorine/chlorine dioxide and halogenated solvents families, there are far fewer spills (see Table 1), and many states have no spills in a given year. To handle this, we fit Poisson regression models, estimated by maximum likelihood. These regressions assume that the probability of experiencing y spills in year t is:

(3) $$\Pr(Y_{it} = y_{it}) = \frac{e^{-\lambda_{it}} \lambda_{it}^{y_{it}}}{y_{it}!}$$

where $\lambda_{it} = \exp(x_{it}\beta)$, and that both the expected number of spills and their variance are equal to λ_{it}.

The Choice of Independent Variables

How a firm responds to the imposition of liability should depend, among other things, on its ability to deflect payment of some or all of the damages to its insurance companies. Aggregate spills rates should, therefore, depend on how insurers react to firms' demand for pollution insurance.

Ideally, we would like to account for these effects by specifying a system of two simultaneous equations, in which the dependent variables are (i) the number of spills, and (ii) the extent of pollution insurance coverage purchased by firms. Unfortunately, as we earlier discussed, data on pollution insurance purchased by firms, and claims paid to firms in relation to spills and contaminated sites, are not available. This forces us to focus on single, reduced-form equations for spill counts (equations (2) and (3)), in which the right-hand side variables are exogenous factors influencing care, and hence spills, either directly or through the demand and supply for pollution insurance.

The variables *x*, therefore, include measures of the state's economic and manufacturing activities; hazardous waste generation per capita; population characteristics (density, membership in environmental organizations); and program characteristics (indicators of presence of provisions for victim compensation, citizen suit, punitive damages, strict liability).

The number of toxic spills should depend on the extent of economic activity involving chemicals. We capture this, and the breakdown of industrial activity by firm size, with the numbers of production units in the industrial and extractive sectors in the state, both at the aggregate level and broken down into "large" and "small" plants. We are forced to use the number of employees to define small and large establishments, since data on the number of firms by *asset* size are not available at the state level. In this paper, we report results obtained by defining small establishments as those with fewer than 20 employees.[12] We take log transformations of these variables to allow for the number of spills to grow at either a decreasing or an increasing rate with the number of firms.

To further capture damages D*,* we create a pair of indicator variables, VICTCOMP and PUNDAMAGE*,* for, respectively, the presence of provisions for victim compensation in the

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[12] Although establishments with fewer than 20 employees account for only about two percent of the total value of shipments from manufacturing firms, they are very numerous, making up about two-thirds of the total number of establishments. We repeated our analyses for other breakdowns into smaller and larger establishments (e.g., establishments with fewer and more than 50 or 100 employees), and obtained qualitatively similar results.

state mini-superfund program, and for whether a state initiating cleanup in the presence of recalcitrant responsible parties may impose punitive damages.

To account for the probability *p* of being targeted by the agency, we construct a dummy (CITSUIT) for whether private citizens can initiate actions against parties responsible for toxic releases. We treat this provision as an effective broadening of the reach of the state environmental agency, because it increases the ability of private citizens to serve as “deputies” for the agency, possibly permitting closer oversight over firm behavior than the agency could achieve by itself.

The regressor at the heart of this paper is, of course, STRICT, our indicator for whether the mini-superfund program prescribes strict liability. We note that STRICT could also influence firms’ perceived probabilities of being targeted by the agency. In the absence of strict liability, the agency may have only limited control over potentially responsible parties, possibly giving firms less incentive to take care (EPA, 1989), with the result that there may be more – or more severe – spills.

In most cases, liability standards are subject to interpretation by the state courts, based on the statutory language, statutory structure, and the common law arguments advanced by the state (ELI, 1995). State laws interpreted to impose strict liability on responsible parties typically give enforcement authority to the state agency, making it possible for the agency to issue unilateral orders to responsible parties, and to refer cases with recalcitrant responsible parties to the state general attorney. The burden of proof is placed on the defendant (the firm alleged to be responsible for the release).

By contrast, under negligence-based liability the burden of proof is on the plaintiff (the state agency), which must show that the responsible party committed a negligent, reckless, or intentionally wrongful act. It is up to the courts to establish the standards of negligence case by case. It is generally argued that under negligence-based liability the state agency will have to spend more resources investigating the intent of parties involved at a contaminated site and will face a smaller universe of parties on which liability may attach. This may lessen the incentive of firms to take care (ELI, 1995).

Table 1. Descriptive statistics

Label	Description	mean	std. dev.
AREA	total area of the state (square miles)	72,824	90,072
POPUL	state population (thousands)	4945.76	5460.24
ALL_MIN	number of mining establishments in the state	583.55	1091.20
MFGESTAB	number of manufacturing establishments in the state	7211.52	8472.52
SMLMFG	number of manufacturing establishments with fewer than 20 employees in the state	4763.28	5747.49
LGMFG	number of manufacturing establishments with 20 or more employees in the state	2366.13	2731.75
SMLMINE	number of mining establishments with fewer than 20 employees in the state	466.80	912.28
LGMINE	number of mining establishments with 20 or more employees in the state	116.77	187.98
ENVORG	number of in-state members of three major environmental organizations, per 1000 residents	8.49	3.54
HAZWASTE	quantity of hazardous waste per capita generated in the state (thousands of lbs)	1.58	2.91
ACID spills	number of reported acids spills per state per year	18.54	34.67
AMMONIA spills	number of reported ammonia spills	10.98	16.55
HALOGENATED SOLVENTS spills I	number of spills of TCA, TCE, METH and PERC	2.44	3.47
HALOGENATED SOLVENTS spills II	number of spills of broader group of halogenated solvents	4.70	12.54
CHLORINE spills	number of spills of chlorine/chlorine dioxide	6.27	9.33
STRICT	State program imposes strict liability	.68	.47
CITSUIT	State program allows citizen suit	.31	.46
PUNDAMAG	Punitive damages charged to uncooperative firms	.56	.50
VICTCOMP	Firms required to compensate victims of release	.24	.43
LAWYER	Number of lawyers working on state mini-superfund cases per million state residents	1.38	1.73
CORTEFF	% civil cases disposed of out of total civil cases filed	95.25	9.73
PCTDEMPR	% votes for democratic candidate in most recent presidential elections	48.04	9.14

While many responsible parties reach consent agreements with the state agency, making litigation necessary over only a fraction of all hazardous waste sites on the agency's priority list, the incentives faced by firms should be influenced by the expected outcome of litigation. This may depend on the aggressiveness of the state agency, which we measure as the number of lawyers working on state superfund cases per million residents (LAWYER); on the perceived efficiency of the state court system, and on the perception of the courts' general tendency to rule in favor of the defendant or the plaintiff in toxic tort lawsuits. We measure state court efficiency by the ratio of all civil cases disposed of to all civil case filed (CORTEFF).[13] Lacking better statistics on state court rulings, we assume that state court preferences for business activity and environmental quality are similar to preferences of the state, and proxy them with the percentage of votes for the democratic candidate in the most recent presidential elections (PCTDEMPR), a widely used political variable.[14]

To control for possible differences in state propensities to report spills to ERNS, we include in the regression model two variables that we believe influence the *reporting* of spills:

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[13] Data from *Court Statistics Project,* National Center for Court Statistics, Williamsburg, VA. By this measure, state court efficiency is lowest in Florida and Connecticut, and is highest in Iowa. Interestingly, there appears to be a small, but negative and significant, correlation between state court efficiency and strict liability: States imposing strict liability appear to have less efficient court systems. Since the litigation generated under the state mini-superfund program is likely to be only a small portion of total civil litigation, we do not believe that a lower degree of court system efficiency is necessarily caused by the additional litigation promoted by the liability structure. It is possible that some states plagued by an inefficient court system may have envisioned strict liability as a way of avoiding lengthy and costly litigation at state superfund sites (strict liability does not place the burden of proof on the plaintiff, reducing the states' costs in preparation for litigation; potentially responsible parties may be lured into out-of-court settlements, effectively by-passing a slow and inefficient court system). As one reviewer suggests, this negative correlation may reflect pressure by interest groups on state legislators: state legislation may pass a more stringent liability standard to please residents and environmental groups, while in reality the inefficient state court system helps potentially responsible parties delay payment of cleanup costs. On balance, these two arguments leave the sign of the coefficient of the state court system efficiency variable unknown a priori.

[14] To capture some of the possible effects of pollution insurance coverage, we also ran some initial regressions that included a dummy for whether the CGL pollution exclusion in that state has been successfully challenged. The coefficient of the dummy variable was close to zero and insignificant. We therefore omit this variable from the specifications we report in the paper.

population density (accidents may be more difficult to conceal in highly populated places), and membership, per 1000 residents, in any of three major environmental organizations (environmental awareness of the population may affect the level of scrutiny and reporting). However, population density may also influence the extent and cost of cleanup, and may encourage firms to avoid releases for fear that they will be reported to authorities by community residents, making the sign of the coefficient of population density unknown *a priori*. Similar considerations apply to the sign of the coefficient of ENVORG. Finally, we include among the regressors the amount of hazardous waste per capita generated in the state.

For both the linear and the Poisson regressions, our first order of business is to determine whether strict liability and the other attributes of a state's mini-superfund program explain the number of spills beyond what is predicted by the extent and type of manufacturing and the reporting variables. To do so, we regress the number of accidental releases in a state on manufacturing and reporting variables, and state program dummies, simply entered additively in the right-hand side of the model. We lag the dummy variables for strict liability, citizen suit, victim compensation, and punitive damages one year to try to avoid possible endogeneity with the dependent variable (number of spills), and to account for the lag, if any, in firms' behavioral responses to new laws.[15]

After establishing these relationships, we attempt to control for unobserved heterogeneity, and then, to see if behavioral responses of firms are structurally different under the two alternative liability regimes, we run separate regressions for states and years with and without strict liability.

7. Results.

We first report our initial OLS and Poisson regressions, testing the strict liability effect while controlling for state industrial activity (by firm size or sector), population, other program features, and proxies for environmental protection. The results are suggestive, but have several possible explanations. To eliminate possibilities, we estimate fixed effects models (to see if the effects are due to unobserved heterogeneity); random effects (where the fixed effects models prove unsatisfactory); and finally split the sample according to liability regime, and estimate paired models to test for reporting effects and for the appropriateness of our basic econometric specification.

A. Initial regressions

As shown in Table 2, the number of spills a state experiences in a year is generally well predicted by the numbers of manufacturing and mining establishments located there, the amount of hazardous waste generated in the state, the degree of environmental awareness of the public, population density, and the policy dummies. Jointly considered, these regressors are significant predictors of the numbers of spills at conventional significance levels and explain a reasonable portion of the variability in the dependent variable. The adjusted R squares in the models for acid and ammonia spills are 67 and 49 percent, respectively.[16]

Looking at the results for the attributes of the state mini-superfund programs (Table 2, regressions A), we find that the coefficient of strict liability is positive and significant: states

[15] We present a simple test of endogeneity of strict liability in Appendix B.
[16] For the Poisson regressions, we compute the t statistics based on misspecification-robust standard errors. The misspecification robust covariance matrix is (F^{-1} V F^{-1}), where V is the Fisher information matrix for the Poisson model, and F is the expected value of the outer product of the score, the score being the vector of first derivatives of the model (see Fahrmeir and Tutz, 1994).

that adopt strict liability continue to have higher rates of toxic spills. Further controlling for prosecutorial discretion of the state agency and likely outcome of litigation through the state court system (regressions B) does not change this result. The effect is robust across different chemical families and specifications, and can be quite large.[17]

Table 2. Spills in fixed facilities: Basic specifications.

	OLS		OLS		Poisson	
Variable	Acids. Dep. Var.: log(count+1)		Ammonia Dep. Var.: log(count+1)		Chlorine Dep. Var.: count	
	A	B	A	B	A	B
Intercept	-1.7198 (-3.805)	-0.1647 (-0.269)	-3.6768 (-7.048)	-4.299375 (-5.777)	-5.1263 (-19.668)	-5.5867 (6.686
log manufact. firms 20+	-0.2766 (-1.841)	-0.3643 (-2.214)	0.2106 (1.125)	0.4209 (1.999)	-0.8101 (-8.628)	-0.2815 (-1.537
log manufact. firms < 20	0.5975 (3.585)	0.7377 (4.150)	0.4792 (2.398)	0.2468 (1.138)	1.5596 (15.854)	1.1258 (6.060
log mining firms 20+	0.3214 (4.515)	0.1357 (1.736)				
log mining firms < 20	0.1082 (1.491)	0.2532 (3.183)				
Hazwaste	0.0100 (0.687)	0.0267 (1.615)	0.0440 (2.632)	0.0286 (1.507)	0.1219 (8.524)	0.1125 (7.758)
log pop. Density	-0.0269 (-2.004)	0.2581 (5.094)	-0.2111 (-4.168)	-0.2511 (-4.149)	-0.0013 (-0.046)	-0.1582 (-2.228)
ENVORG	0.2446 (5.474)	-0.0063 (-0.400)	-0.0864 (-5.579)	-0.0816 (-4.274)	-0.0970 (-11.011)	0.0087 (0.481)
Strict (lagged)	0.4408 (5.214)	0.3510 (3.708)	0.3138 (3.008)	0.2797 (2.443)	0.7392 (12.706)	0.5051 (4.792)
citizen suit (lagged)	-0.2475 (-2.503)	0.2567 (3.411)	0.2568 (2.246)	0.1407 (1.457)	0.4066 (9.208)	-0.1029 (-1.030)
Punitive damages (lagged)	-0.0744 (-0.866)	0.1767 (1.792)	0.1986 (1.830)	0.0488 (0.388)	-0.1982 (-4.186)	-0.0967 (-0.858)
Victim compens. (lagged)	0.2692 (3.711)	-0.1235 (-1.184)	0.2568 (2.099)	0.2426 (1.898)	-0.0998 (-0.557)	0.1591 (1.367)
LAWYER		-0.0303 (-1.349)		-0.0385 (-1.346)		-0.1082 (-2.698)
CORTEFF		-0.2320 (-0.597)		-0.1407 (-0.288)		0.5336 (1.2753)
PCTDEMPR		-4.2266 (-5.752)		2.2904 (2.467)		-2.8074 (-3.338)
adj. R^2	0.6649	0.6762	0.4684	0.4912		
F statistic	70.252	49.321	39.281	27.311		
Log Likelihood					-3366.59	-2635.70
N	384	325	392	328	391	328

T statistics in parentheses. Poisson regression: misspecification-consistent t statistics.

Table 2 (cont d). Spills in fixed facilities: Basic specifications.

[17] The regressions using the broad halogenated solvents data suggest that the number of spills of these chemicals are up to 200% greater in strict liability states than what would be predicted by the other independent

Variable	Poisson Halogenated Solvents Dep. Var.: count		Poisson TCA, TCE, METH, PERC Dep. Var.: count	
	A	B	A	B
Intercept	-4.5603 (-2.669)	-8.3095 (-8.271)	-6.1816 (-8.801)	-5.2316 (-5.464)
log manufact. firms 20+	0.1575 (0.395)	0.5193 (2.027)	0.4691 (1.666)	1.0483 (4.055)
log manufact. firms < 20	0.7071 (1.557)	0.7040 (2.623)	0.3823 (1.411)	-0.0829 (-0.334)
Hazwaste	0.0731 (3.008)	0.0838 (3.138)	0.0495 (2.492)	0.0137 (0.723)
log pop. Density	0.1073 (0.822)	-0.1970 (-1.927)	0.0960 (1.209)	0.0516 (0.560)
ENVORG	-0.1548 (-2.871)	0.0087 (0.287)	0.0078 (0.325)	0.0910 (3.473)
Strict (lagged)	0.2631 (0.547)	0.5457 (3.599)	0.5392 (3.529)	0.2082 (1.586)
citizen suit (lagged)	0.7798 (1.914)	-0.1467 (-1.189)	0.2625 (1.941)	0.0053 (0.035)
Punitive damages (lagged)	-0.2843 (-1.690)	-0.0776 (-0.433)	-0.4124 (-2.912)	-0.0065 (-0.042)
Victim compens. (lagged)	-0.3088 (-1.518)	-0.3890 (-2.532)	-0.5205 (-4.089)	-0.4198 (-2.881)
LAWYER		0.0048 (0.094)		-0.0074 (-0.174)
CORTEFF		0.6026 (0.706)		0.2779 (0.366)
PCTDEMPR		-3.8122 (-2.934)		-4.9037 (-3.875)
Log Likelihood	-2216.34	-1452.65	-251.23	-281.84
n	392	328	392	328

T statistics in parentheses. Poisson regression: misspecification-consistent t statistics.

The effects of other attributes of the state programs appear to vary with the specification and with the chemical being analyzed. Excluding the dummy variables that capture the other aspects of the state programs generally does not change the coefficients of strict liability very much, nor their statistical significance.

The coefficients of population density and membership in leading environmental organizations frequently switch sign from one regression to the next, probably as a result of the

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variables alone.

moderate, but significant, correlation between these variables. By contrast, the quantity of hazardous waste generated per resident is almost always significantly and positively related to the frequency of spills. With values ranging from 0.04 to 0.12, however, the effect of HAZWASTE, which serves as a control for the amount of activity involving substances actually classified as toxic waste, is not very large.

Of particular interest is the possible firm-size effect. To find whether the number of small and large establishments have different effects on spills, we performed F tests (for ammonia and acid spills) and likelihood ratio tests (for the Poisson models) of the null hypothesis that, in each equation A of Table 2, the coefficients of large firms are equal to their small-firm counterparts. We reject the null for spills of acids, chlorine, and the broader halogenated solvent family. For these families, the number of small firms is positively and significantly associated with the number of accidents, but the number of large firms is not. But the contributions of small and large firms to the frequency of ammonia spills and the four halogenated solvents are not statistically different.

Adding variables that account for the aggressiveness of the state in forcing responsible parties to pay for cleanup, and that account for the expected outcome of litigation over responsibility at contaminated sites (regressions B) does not alter the basic results about the sign and magnitude of the coefficient of strict liability. F tests (for the linear regressions) and Wald tests (for the Poisson regressions) indicate that these additional variables as a whole significantly improve the fit of the model. In most regressions, the number of mini-superfund case lawyers has the expected negative effect on spills, whereas the coefficient of the court efficiency variable tends to switch sign, depending on the chemical family. However, t statistics indicate that their coefficients of the latter variable are for the most part insignificant at the conventional levels. Popular support for Democratic presidential candidates generally has a strong and negative effect on the number of spills.

Regression results from controlling for the composition of production activities are reported in Table 3. We control for the composition of manufacturing in the state by including as explanatory variables the numbers of plants, in logs, for industries that are major users of the chemicals. For instance, we predict annual chlorine gas and chlorine dioxide spills using the numbers of chemical plants (chlorine being a feedstock for other intermediate and finished chemical products), paper and allied products plants, food processing establishments, and textiles plants, all of which use these substances for bleaching purposes. Similarly, chlorinated solvents are used as a chemical feedstock, for metal cleaning purposes in manufacturing, and in the furniture and plastics industries. Although widely used for dry cleaning and in the service/repair industry, we do not try to explicitly control for the businesses in the latter sectors: population density should capture their numbers. [18]

In general, this improves the predictive power of the models, but has a mixed effect on the strict liability dummy. For spills involving halogenated solvents, the coefficient of the strict liability dummy becomes insignificant. One possible explanation for this finding is that the presence of other environmental regulations for these substances overwhelms the incentives posed by liability. When we included state regulations and standards for emissions of halogenated solvents (reported in Sigman, 1996), though, we found no evidence of a significant correlation with the number of spills involving these substances. Other provisions of

[18] Table 3 excludes acids. Because of their widespread use in manufacturing and mining, we do not try to control for the composition of the industrial sector.

the state program (victim compensation and punitive damages) appear still to be associated with a lower number of spills.[19, 20]

For ammonia and chlorine spills, strict liability continues to be positively and significantly associated with the number of spills, over and above what is predicted by the amount of manufacturing in the various industries. Hence, we focus on these chemicals, as well as on acids spills, in our next analyses.

B. Interpreting initial results

That the presence of strict liability is a positive and significant predictor of spills is consistent with several possible explanations.

First, the effect could be real: strict liability could give firms fewer incentives to take care than a negligence standard. Second, the estimated coefficient of strict liability may capture the effects of other omitted factors influencing the number of spills. To account for unobserved heterogeneity, we re-specify our models to include fixed and random effects.

Third, it is possible that the strict liability dummy captures a heightened reporting effect on the part of both firms and authorities – that states which have adopted strict liability are populated by individuals, firms and government officials with a higher propensity to report spills. Fourth, the positive and statistically significant coefficient of the strict liability dummy may be an artifact of the econometric specification. For instance, if the true coefficients of the

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[19] Excluding these other attributes makes the strict liability dummy negative, but insignificant.

[20] The coefficients of the variables measuring the number of firms in the various manufacturing sectors often have counterintuitive signs in the halogenated solvents equations of table 3. We blame this result to the high degree of collinearity between those regressors: the coefficient of correlation between counts of plants varies between 0.83 and 0.94. When we go beyond controlling for manufacturing composition, to also include firm size, there is little effect on the predictive power of our regression models, and the sign, magnitude and significance of the coefficient of the strict liability dummy does not change much.

major variables in the model differ across states that do and do not have strict liability provisions, imposing that they be equal may result in biased estimates.

Formal testing of the third and fourth explanations requires that we split the data into two separate sets, and fit separate regressions for observations from states and years with and without strict liability hazardous waste laws. Based on these separate regressions, we perform two Wald tests. The first is a test of the “reporting effect,” the null hypothesis of which is that the coefficients of ENVORG and population density are equal across the two regimes.

The second Wald test seeks evidence that under strict liability small plants contribute disproportionately to the number of spills – as would be the case if, for example, strict liability resulted in risky operations being shifted to smaller firms. The null hypothesis of the second Wald test is, therefore, that the variables measuring small plant effects and those measuring large plant effects have equal coefficients under the two regimes.

In the next section we report on the regressions accounting for unobserved heterogeneity. Following that, we present the tests of the reporting effect and of the firm-size effect.

Table 3. Spills in fixed facilities: Composition of manufacturing.

	OLS	Poisson	Poisson	Poisson
Variable	**Anhydrous Ammonia**	**Chlorine**	**Halogenated Solvents**	**TCA, TCE, METH, PERC**
intercept	-2.6282 (-5.892)	-3.3646 (-7.186)	-2.9812 (3.349)	-4.1433 (-1.050)
hazwaste	0.0600 (3.469)	0.0143 (7.783)	0.0494 (2.093)	0.0293 (1.279)
log chemical plants	-0.0518 (-0.370)	0.6728 (5.272)	0.8086 (2.226)	0.3805 (1.957)
log food processing plants	0.7239 (6.730)	0.5970 (4.083)		
log textiles plants		-0.0599 (-0.972)		
log furniture plants			-1.5308 (-6.543)	-0.8461 (5.441)
log paper & allied products plants		-0.4003 (-2.484)		
log rubber & plastics plants			-0.6171 (-1.419)	-0.6522 (-2.365)
log primary metals plants	-0.2386 (-1.815)			
log fabricated metals plants	0.3267 (1.756)		0.3296 (0.499)	-0.5482 (-1.234)
log industrial machinery plants			-0.4671 (-1.088)	0.7218 (1.505)
log electronic & electric plants			3.3622 (3.885)	1.2874 (4.679)
log transportation equipment plants			0.7852 (3.623)	1.0217 (6.735)
log instruments plants			-1.7109 (-3.543)	-0.4646 (-2.214)
log pop. Density	-0.0322 (-0.661)	0.0029 (0.037)	0.1451 (1.401)	0.2809 (2.857)
Env. Organization membership	-0.0768 (-5.244)	-0.0584 (-2.920)	-0.1576 (-2.039)	0.0046 (0.170)
Strict (lagged)	0.2582 (2.666)	0.4847 (4.032)	-0.2970 (-0.883)	0.1925 (1.373)
citizen suit (lagged)	0.1429 (1.633)	0.1842 (1.800)	0.4738 (1.499)	-0.0708 (-0.670)
Punitive damages (lagged)	0.2862 (2.955)	-0.0663 (-0.596)	-0.1766 (-1.227)	-0.5078 (-4.514)
Victim compens. (lagged)	0.0849 (0.759)	0.0626 (0.380)	-0.1994 (-0.861)	-0.6702 (-4.587)
adj. R^2	0.5585			
s^2	0.5327			
F statistic	43.777			
Log Likelihood		-3405.85	-2676.01	-344.98
n	373	391	390	390

T statistics in parentheses. Poisson regressions: misspecification-consistent t statistics.

C. Unobserved heterogeneity

It is possible that spills counts are influenced by unobserved state characteristics that persist over time, such as the state regulatory stringency, the state's experience in dealing with toxic pollution problems, insurers' reactions to liability, etc. To account for unobserved heterogeneity in our data, we re-specify our regression equations to include fixed effects and random effects.

In the case of acids and ammonia,[21] the fixed effects model is:

(4) $$\log(y_{it}+1)=\alpha_i+\tilde{x}_{it}\beta+\varepsilon_{it}$$

where the αs are state-specific intercepts, and $\tilde{x}$ includes only time-varying regressors (see Greene, 1997).

Results from the fixed effects models for acid and ammonia spills are reported in table 4. Although an F test supports the fixed effects model as opposed to a model with a common intercept, and a Hausman test supports the fixed effects model over the relevant random effects model,[22] it is hard to make out much from the fixed effects model for acid spills. All coefficients are insignificant, including that of strict liability, which is negative.

The fixed effects model is better behaved for ammonia spills. In this model, four coefficients are individually significant at the 10 percent level or better: the coefficients of small manufacturing plants, the citizen suit dummy, state superfund lawyers per million residents, and the percentage of popular votes cast for the Democratic presidential candidate. The coefficient of strict liability is now negative and insignificant.

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[21] The fixed effects model applied to a Poisson regression of chlorine spill did not attain convergence.

Table 4. Spills in fixed facilities: Panel data models. (T statistics in parentheses)

Variable	Acids		Ammonia		Chlorine
	State random effects	State fixed effects	State random effects	State fixed effects	Negative binomial
Intercept	-1.3082 (-1.310)	--	-6.7930 (-5.321)	--	-5.9405 (-7.318)
log manufact. firms 20+	-0.2657 (-0.955)	0.3210 (0.479)	-0.2293 (-0.652)	-0.2440 (-0.325)	-0.2471 (-0.834)
log manufact. firms < 20	0.7406 (2.428)	0.7022 (0.834)	1.0638 (2.913)	3.2112 (3.247)	1.1231 (6.749)
log mining firms 20+	0.0669 (0.673)	0.0261 (0.161)			
log mining firms < 20	0.2434 (2.098)	0.4403 (1.209)			
Hazwaste	0.0122 (0.394)	--	0.0218 (0.553)	--	0.1092 (7.690)
log pop. Density	0.2311 (2.412)	0.5845 (0.356)	-0.2067 (-1.807)	-2.0714 (-1.062)	-0.1632 (-2.632)
ENVORG	-0.0223 (-0.805)	--	-0.8138 (-2.258)	--	-0.0089 (-0.081)
strict (lagged)	0.0281 (0.278)	-0.0927 (-0.702)	0.1483 (1.357)	-0.0402 (-0.264)	0.3999 (4.174)
citizen suit (lagged)	0.2284 (1.865)	0.2823 (1.355)	0.3795 (2.577)	0.6030 (2.412)	-0.0990 (0.982)
punitive damages (lagged)	-0.1577 (-1.122)	-0.1657 (-1.568)	-0.1164 (-1.251)	-0.1389 (-1.085)	-0.1163 (-1.072)
victim compens. (lagged)	-0.8147 (-0.969)	-0.1980 (-0.948)	-0.3070 (-1.889)	-0.3459 (-1.383)	0.1462 (1.231)
LAWYER	-0.0273 (-0.153)	-0.0063 (-0.285)	-0.0434 (-2.234)	-0.0471 (-1.834)	-0.0476 (-0.330)
CORTEFF	0.0902 (0.331)	0.1344 (0.417)	-0.3981 (-1.349)	-0.2707 (-0.699)	0.3274 (0.999)
PCTDEMPR	-2.6344 (-2.914)	-1.8028 (-1.299)	4.6656 (4.537)	3.0902 (1.912)	-1.8262 (-2.039)
adj. R^2	0.6555	0.8334	0.4293	0.7744	
F statistic		29.46		21.29	
Log Likelihood					2811.99
N	325	331	325	338	328

To get further insights about unobserved heterogeneity, we also fit random effects models.[23] For the acid and ammonia spills, the random effects follow the usual assumption of

[22] Here, the relevant random effects model is a model that, like the fixed effects model, only includes time-varying regressors.

[23] Random effects models differ from fixed effects models in two important respects. First, in contrast to fixed effects models, they rely on the assumption that the causes of unobserved heterogeneity are uncorrelated with the independent variables included in the model. Second, their estimated coefficients are more efficient than the estimates of a similarly specified fixed effects model.

normality (see Greene, 1997).[24] For the chlorine spills, we fit a particular type of random effects model, the negative binomial model. The negative binomial model assumes that λ_{it} is a random variable centered around $x_{it}\beta$, and that the marginal distribution of λ_{it} is a gamma. The probability that a certain value of the dependent variable is observed is now computed as:

(5) $$\Pr(Y_{it} = j) = \int_0^{\infty} \frac{e^{-\lambda_{it}} \lambda_{it}}{j!} dF(\lambda_{it}),$$

where F(•) is the gamma cdf.

The results of the random effects models are also reported in Table 4 and are quite instructive. In the chlorine equation, the coefficient of the strict liability dummy remains positive and significant. In the acid and ammonia equations, strict liability is still positively associated with the number of spills, but its coefficient is no longer significant. Small firms are always positively and significantly associated with spills, but the coefficient of large firms is negative and insignificant.

To summarize, three important results emerge from the models allowing for unobserved heterogeneity. First, unobserved heterogeneity *may* be a possible explanation for our earlier results about the effects of strict liability, but only for *some* of the chemical families we analyze. Second, the coefficients of two program attributes interpreted to increase firms' liability – provisions for punitive damages and for victim compensation – are now almost always *negatively* associated with spills, although the significance of their respective

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[24] Specifically, the error term of the linear regression model, ε, is be broken down into two components: a first disturbance, ν_i, that is normally distributed over the states, but remains unchanged over time within a state, plus an i.i.d. portion (η_{it}). Both the ν_i's and the η_{it}'s are uncorrelated with the included regressors. The ν_i's introduce correlation between the observations coming from one states, and require use of GLS estimation technique (Greene, 1997).

coefficients vary with the chemical family and model. The coefficient of provisions allowing for citizen suits is positive, suggesting that such provisions have made citizens more aware of spills. Third, regardless of the sign of the lagged strict liability dummy, small manufacturing firms appear to be consistently associated with more numerous spills.

D. Reporting Effect and Structural Change

In Table 5 we report the results of regressions for acids, ammonia and chlorine spills that isolate the observations from states and years with strict liability from those without it.[25,26]

The null hypothesis of equal propensities to report spills in states and years with *versus* without strict liability implies the equality of the coefficients on population density and environmental awareness. The Wald test clearly rejects this null hypothesis in the acids and chlorine regressions. In states and years with strict liability, membership in environmental organizations is negatively and significantly associated with spills: The increased reporting by an environmentally sensitive populace appears to be more than compensated for by firms' tendency to increase safety precautions for fear of being reported. Patterns are more difficult to recognize for population density, and for both variables in states with negligence-based liability.

[25] States which adopted strict liability after 1987 have observations in both sets of regressions. The liability rules in force at the beginning of each year determine to which regression an observation is assigned.

[26] To save space, we only report results from specifications that omit variables capturing prosecutorial discretion of the state agency and likely outcome of litigation. Results are qualitatively very similar when these variables are added in the model.

Table 5. Spills in fixed facilities: Separate regressions.

Strict liability (n=277)	**Acids (OLS)**	**Ammonia OLS**	**Chlorine Poisson***
constant	-3.4209 (-6.361)	-3.9280 (-6.415)	-4.4401 (-3.677)
log population density	0.0579 (1.289)	-0.1615 (-3.206)	-0.0082 (-0.076)
envorg	-0.0858 (-5.443)	-0.0677 (-3.829)	-0.0821 (-2.615)
hazwaste	0.0110 (4.408)	0.0750 (2.555)	0.1234 (4.009)
log manufac. 20 +	-0.2947 (-1.632)	0.0455 (0.225)	-0.8090 (-3.578)
log manufac. < 20	1.0810 (5.581)	0.7141 (3.288)	1.5528 (8.384)
negligence-based liability (n=115)	**Acids OLS**	**Ammonia OLS**	**Chlorine Poisson***
constant	0.0523 (0.055)	-1.5881 (-1.156)	0.5775 (0.741)
log population density	-0.1379 (-1.1934)	0.0069 (0.041)	0.2511 (1.967)
envorg	0.0621 (2.487)	-0.1275 (-3.507)	-4.41e-5 (-0.001)
hazwaste	0.0380 (2.454)	0.0110 (0.471)	0.0516 (3.850)
log manufac. 20 +	1.0855 (3.329)	-0.3400 (-0.717)	0.3337 (0.854)
log manufac. < 20	-0.7985 (-2.471)	0.8438 (1.795)	-0.1300 (-0.340)
Wald test on reporting variables	25.50	2.32	21.00
Wald test on small and large plants	40.53	3.43	36.97

T stats in parentheses. Poisson regression: misspecification-consistent t statistics.

Wald test on reporting variables test the null hypothesis that the coefficients of LPOPDENS and ENVORG are equal across the two liability regimes. The **Wald test on small and large plants** tests the null hypothesis that the coefficients of log small and log large plants are equal across the two liability regimes. For large samples, both tests are distributed as chi squares with 2 degrees of freedom under the null hypothesis. At the 5% significance level, the critical value is 5.99.

The table also displays the results of the Wald test of the hypothesis about firm size. With the exception only of ammonia spills, the Wald test rejects the null hypothesis that the coefficients of small and of large plants are the same across the two liability regimes. The estimation results show clearly that, in strict liability regimes, the number of spills increases with the number of *smaller* plants. By contrast, the number of larger plants is typically not significantly associated with the number of spills. In negligence-based regimes, this result is reversed in the acids regressions, while neither firm-size variable is a significant predictor of the number of ammonia and chlorine spills.

The estimated equations of Table 5 predict that the "average" state (i.e., a state with the average number of small and large manufacturing establishments) should have approximately the same number of spills under either liability regime. For instance, in the case of acids the predicted median number of spills is 9.5 under strict liability and 10.9 with negligence-based liability; the two figures are not statistically distinguishable.

However, states that have adopted strict liability provisions differ from other states in one important respect: they typically have more manufacturing establishments. States with strict liability boast an average of 5,402 small establishments (against 3,792 for negligence states), and 2,618 larger plants (against 1,895). (In both types of state, the proportion of small to large plants is roughly 2 to 1.[27])

Taking these differences into account, the two separate regression equations in Table 5 imply that the predicted number of spills in a year *is* significantly greater in states with strict liability. When differences in the actual numbers of plants are allowed for, the predicted median number of acid spills in strict liability states becomes 15.6, *versus* 11.9 in negligence states.

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[27] These statistics tend to argue against the notion that larger firms spin off risky activities to smaller firms upon the adoption of strict liability: there are no differences between "strict liability" states and "negligence" states in their small-firm fractions. Over the course of our sampling period, 1987-1995, the fraction of small firms (20 or fewer employees) changed very little – rising from 67% to 70% even as almost half the states adopted strict liability.

This is consistent with the results of Table 2, where states with strict liability were seen to experience more spills. The other chemical families produce similar results. We conclude that *differences in the number of plants* and in *the higher propensity of small firms to experience spills* may be one reason why accidents appear to be more frequent in states with strict liability.

When we include other attributes of the mini-superfund programs into the split regressions, their coefficients generally have negative signs. To illustrate, only when we regress separately on strict-liability states do the coefficients on the punitive damages and victim compensation dummy variables become uniformly negative across chemical families.[28] For acid spills in states with strict liability, we get the following estimated equations (t statistics in parentheses):

(6)

Ln (acid spills+1)	= -3.6070	+0.0993* lpopdens	0.0752*envorg	+0.1200*hazwaste
	(-6.701)	(2.065)	-4.615)	(4.582)

-0.4623*ln(LGMFG)	+1.2699*ln(SMLMFG)	-0.1955*pundlag	+0.0825*citlag	-0.2472*victlag
(-2.419)	(6.149)	(-1.917)	(0.835)	(-2.098)

In equation (6), the coefficients of PUNDLAG and VICTLAG are negative and significant. Together, these provisions imply reductions in the number of acids spills of 20 to 26 percent. CITLAG is positive, if insignificant. The corresponding regression for states and years *without* strict liability reveals that the effects of these variables are positive, but not statistically significant.

8. Discussion and conclusions.

We have analyzed the patterns of spills and accidents involving chemicals in an effort to answer the question: Has strict liability encouraged firms to take care and thus reduced the number of accidents and spills? Because the predictions from the theoretical literature are ambiguous, we have turned to an empirical analysis of this issue. We have exploited the variation in the liability provisions of state superfund programs, looking for additional effects over and above those created by the federal Superfund program.

Our results vary with the chemicals analyzed. This is reasonable given the various regulations and uses of the chemicals, and the diverse industries in which they are used. For some of these chemicals (halogenated solvents), there does not seem to be much difference in spill rates between states with and without strict liability provisions in their cleanup programs, after we account for the number of plants and for the composition of manufacturing.

For other chemicals (acids, chlorine, and ammonia) our initial empirical evidence suggests that, even after accounting for manufacturing and population variables, spills may be more numerous in states that have adopted strict liability. Further investigation suggests that for some chemical families, this difference may be the result of unobserved state-level heterogeneity. The liability structure *per se* is not significant. This could be due to the different industrial activities that use the specified chemicals, to their different market structures, locations and interaction with state regulatory agencies which may have acted to reduce the incentives of liability, and possibly to different environmental standards. These same panel-data regressions also suggest that small firms might be positively associated with spills, regardless of the liability structure, a result that is consistent with the existence of economies of

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[28] In the pooled regressions of Table 2, their effects were mixed: both PUNDLAG and VICTLAG were seen to have both positive and egative coefficients, depending on the specification and the chemical family. The results of the fixed and random effects models are similar to the results for states with strict liability.

scale in safety, or with the possibility that the liability regime cannot alter small firms' expected disbursements for pollution releases.

By contrast, an alternative explanation, supported by the results of separate regressions for states with and without strict liability, is that small and large plants (our proxy for small and large firms) may contribute differently to spill rates, depending on whether the state's hazardous wastes policy is based on strict liability or negligence. Specifically, in states that have adopted strict liability, small firms appear responsible for a larger share of spills involving these chemicals. Since states that have adopted strict liability have, on average, more manufacturing firms, and more small firms (in absolute terms), this effect is magnified, leading to greater numbers of spills in states with strict liability laws in place.

The small-firm finding could be the result of deliberate firm decisions about their privately optimal levels of care under different liability regimes. The result may also be explained by larger firms subcontracting riskier operations to smaller, more judgement-proof firms. In principle, it could also be the result of economies of scale in safety, but if that were the case there is no reason why states with and without strict liability should differ in the safety of their small firms. These questions cannot be resolved using these aggregate data.

To summarize, we have found evidence that strict liability *can* increase the frequency of accidental releases of toxic into the environment. Further research, preferably based on firm-level data, is needed to ascertain the reasons why such effects are seen for some chemicals but not others, whether production processes are indeed shifted to smaller firms, and whether a state's adoption of strict liability is potentially endogenous with the incidence of toxic spills in that state.

References

Action, Jan P. and Lloyd Dixon (1992), *Superfund and Transaction Costs. The Experiences of Insurers and Very Large Industrial Firms*, Santa Monica: The RAND Corp.

Alberini, Anna and David Austin (1997), "Off and On the Liability Bandwagon: Explaining State Adoptions of Strict Liability in Hazardous Waste Programs," Resources for the Future Discussion Paper QE98-08, December 1997, Washington, DC.

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

Beard, Randolph T. (1990), "Bankruptcy and Care Choice," *RAND Journal of Economics*, 21 (4), 626-634.

Environmental Law Institute (1993). "An Analysis of State Superfund Programs: 50-State Study. 1995 Update," prepared for the US Environmental Protection Agency, Washington, DC, December.

Environmental Law Institute (1995). "An Analysis of State Superfund Programs: 50-State Study. 1993 Update," prepared for the US Environmental Protection Agency, Washington, DC, December.

Fahrmeir, Ludwig and Gerhard Tutz (1994). Multivariate Statistical Modelling Based on Generalized Linear Models (New York: Springer-Verlag).

Fogleman, Valerie M. (1992). *Hazardous Waste Cleanup, Liability, and Litigation* (Westport, Conn.: Quorum Books)

Gastel, Ruth (1998). "Environmental Pollution: Insurance Issues," Insurance Information Association,Washington, DC.

Greene, William H. (1997), *Econometric Analysis*, 3rd edition (Englewood Cliffs, NJ: Prentice-Hall).

King, Susan M. (1988). "Lenders Liability for Enviromental Law," *Environmental Law*, 18, 241-291.

Larson, Bruce A. (1996), "Environmental Policy Based on Strict Liability: Implications of Uncertainty and Bankruptcy," *Land Economics*, 72 (1), 33-42.

Macauley, Molly K., Michael D. Bowes and Karen L. Palmer (1992), *Using Economic Incentives to Regulate Toxic Substances*. (Washington, D.C.: Resources for the Future.)

National Research Council (1993), *In Situ Bioremediation*. *When Does It Work?* (Washington, DC: National Academy Press).

National Research Council (1994), *Alternatives for Ground Water Cleanup*, (Washington, DC: National Academy Press).

Opaluch, James J. and Thomas A. Grigalunas (1984), "Controlling Stochastic Pollution Events through Liability Rules: Some Evidence from OCS Leasing," *RAND Journal of Economics*, 1984, 15 (1), 142-151.

Pitchford, Rohan (1995). "How liable Should a Lender Be? The Case of Judgment-Proof Firms and Environmental Risk," *American Economic Review,* 85, 1171-1186.

Ringleb, Al H. and Steven N. Wiggins (1990), "Liability and Large-Scale, Long-Term Hazards," Journal of Political Economy, 98 (31), 574-595.

Shavell, S. (1984), "A Model of the Optimal Use of Liability and Safety Regulation," *RAND Journal of Economics,* 15, 271-280.

Sigman, Hilary (1996), "Cross-Media Pollution: Responses to Restrictions on Chlorinated Solvent Releases," *Land Economics*, 72 (3), 298-312.

Tietenberg, Tom H., (1989), "Indivisible Toxic Torts: The Economics and Joint and Several Liability," Land Economics, 65 (4), 305-319.

U.S. Environmental Protection Agency, Office of Emergency and Remedial Response (1989), "An Analysis of State Superfund Programs: 50-State Study," Washington, D.C.

U.S. Environmental Protection Agency, Office of Emergency and Remedial Response (1990), "An Analysis of State Superfund Programs: 50-State Study. 1990 Update," Washington, D.C.

U.S. Environmental Protection Agency, Office of Emergency and Remedial Response (1991), "An Analysis of State Superfund Programs: 50-State Study. 1991 Update," Washington, D.C.

U.S. Government Accounting Office (1987), "Hazardous Waste. Issues Surrounding Insurance Availability," Report to the Congress, PB88-123138, Washington, DC.

Wentz, Charles A. (1989), *Hazardous Waste Management* (New York: McGraw-Hill).

APPENDIX A. Properties of chemicals.

Chlorine is a naturally occurring, greenish yellow gas with an irritating odor, or present in liquid solutions, and is used in making solvents, many chemicals, synthetic rubber, plastics, disinfectants, and chlorine bleach cleaners. Chlorine is acutely toxic to aquatic life. Chlorine dioxide is a gas with a pungent odor, and is normally diluted to less than 10% in cold solution to reduce its explosive properties. It is sold as a hydrate in frozen form and is used for bleaching wood pulp, oils, textiles and flour, and in water treatment. Both of these gases can cause irritation and severe burning of the eyes, nose, and throat, tearing, coughing and chest pain. Higher levels burn the lungs and can cause a buildup of fluid in the lungs (pulmonary edema) and death. Both gases are highly reactive and explosive in fire.

Ammonia is a highly corrosive and reactive gas that can severely irritate the lungs and burn the skin and the eyes, leading to permanent damage. It is found as a colorless gas and in water solution, and is used in making fertilizers, plastics, dyes, synthetic fibers, glues, animal foods and explosives. It is also used in the treatment and refining of metals.

METH is a colorless volatile liquid used in food, furniture and plastics processing, and in paint removers, and in degreasing and cleaning fluids. TCE is used as a solvent for degreasing and dry cleaning, and in printing inks, paints, lacquers, varnishes, and adhesives. TCA is used in making other chemicals and adhesives, and as a solvent in cleaning metal and in cleaning plastic molds. It is also used to make other organic chemicals. These halogenated solvents tend to cause unconsciousness, and irregular heart beat, and may result in death at high exposures. Long term or extremely high exposures may damage the liver and brain, and cause skin damage or burns. They are suspected carcinogens in humans, and trichloroethylene has been associated with reproductive problems. . These chemicals are subject to a variety of federal statutes (see Macauley et al., 1992), including the Clean Air Act, which lists them as hazardous air pollutants. The National Research Council (1994) lists TCE, PERC, METH and TCE among the 25 most frequently detected substances at sites with contaminated ground water, with TCE and PERC being ranked first and third, respectively.

Cleanup of groundwater contaminated by halogenated solvents is particularly difficult. Traditional pump-and-treat techniques tend to “miss” them due to their high density and tendency to form “columns” or “fingers” that do not easily mix with the surrounding groundwater and can re-contaminate the groundwater as pumping and treatment take place (National Research Council, 1994). Bioremediation options are also limited for this kind of solvent (National Research Council, 1993).

The additional chlorinated solvents in the more comprehensive group of halogenated solvents have similar uses to METH, PERC, TCA and TCE.

Appendix B. Testing endogeneity of strict liability.

To test whether strict liability is endogenous with the number of spill events (the dependent variable in the models we estimate in this paper) we propose the following test procedure. We assume that log spills, y_{it}, depend on a set of variables measuring economic activity and generation of toxics in the state, and on a variable, z_{it}^* , measuring state propensity to adopt strict liability:

(1) $$y_{it} = x_{it}\beta + z_{it}^*\gamma + \varepsilon_{it}$$

where ε is a normally distributed i.i.d. error term. Following Alberini and Austin (1997), we assume that z_{it}^*, state propensity to maintain strict liability, depends on a set of variables proxying the net benefits of strict liability over the alternative regime. Specifically, we assume that:

(2) $$z_{it}^* = w_{it}\delta + \eta_{it},$$

where w_{it} is a vector of state characteristics influencing the net benefits of strict liability, and η is a standard normal error term. Strict liability is present in state i at time t (z_{it}=1) if z_{it}^*>0, and is absent (z_{it}=0) otherwise. The error terms of the two equations are allowed to be correlated with one another for equal i and t, resulting in endogeneity of z_{it}^* (and hence z_{it}) and y_{it}.

To develop our endogeneity test, we factor the joint distribution of z_{it}^* and y_{it} into the marginal distribution of z_{it}^* (which is a standard normal) and the distribution of y_{it}, conditional on z_{it}^* (which is a normal). We use such factorization to compute the joint likelihood of liability configuation and number of spills. The joint likelihood is the probability that z_{it}^*>0 (and hence strict liability is observed) or that z_{it}^*≤0 (negligence-based liability is observed), times the density of y_{it}, conditional on strict liability or negligence-based liability. The probability that strict liability is observed is then $\Phi(w_{it}\delta)$, whereas the expected value of log spills, conditional on strict liability being in place is $x_{it}\beta + z_{it}\gamma + \sigma_{12}\frac{\phi(w_{it}\delta)}{\Phi(w_{it}\delta)}$. The expected value of log spills, conditional on liability not being in place, is $x_{it}\beta + z_{it}\gamma - \sigma_{12}\frac{\phi(w_{it}\delta)}{1-\Phi(w_{it}\delta)}$. This leads to an "augmented" regression for chemical spills.

The test procedure (adapted from Rivers and Voung, 1988) is as follows:

A. Fit a probit model in which the dependent variable is z_{it} and the set of right-hand set variables is w_{it} to get $\hat{\delta}$.

B. Run OLS on the "augmented" regression in which the dependent variable is log spills, y_{it}, and the independent variables are x_{it}, z_{it} and λ_{it}, where $\lambda_{it} = \frac{\phi(w_{it}\hat{\delta})}{\Phi(w_{it}\hat{\delta})}$ if z_{it}=1 and

$\lambda_{it} = -\frac{\phi(w_{it}\hat{\delta})}{1-\Phi(w_{it}\hat{\delta})}$ if z_{it}=0. It can be shown that the coefficient of λ_{it} in the augmented regression is an estimate of σ_{12}, the covariance between ε and η.

C. Let ξ denote the square of the asymptotic t statistic for $\hat{\lambda}_{it}$ from step B. ξ serves as our test of endogeneity. Under the null hypothesis that σ_{12}=0 (z_{it} is not endogenous with log spills), ξ is distributed as a chi square with one degree of freedom.

We applied this procedure to the acids and ammonia spills. We select z_{it} to be the indicator for strict liability in the previous year, and following Alberini and Austin (1997), we specify w_{it} to include (a) the lagged values of manufacturing and mining establishments with more and less than 20 employees; (b) measures of effectiveness of the state water and air quality programs; (c) measures of educational attainment of state residents; (d) estimates of the number of hazardous waste sites in the state; (e) state expenditure per capita, and percent of state budget dedicated to environmental programs, and (f) percent of votes for the democratic candidate in the most recent presidential elections. Alberini and Austin argue that these variables capture the net benefits of the program, defined as the reduction in the expected health damages incurred by the population exposed to accidental releases of toxics at contaminated sites where mitigation is subsequently undertaken, [29] minus the costs of the program. The cost of the program should be affected by the liability regime and program attributes, and by the type (size) of firms in the state.

The vector x_{it} includes log manufacturing and mining establishments with more and less than 20 employees, log population density, HAZWASTE, ENVORG, the number of lawyers working on state superfund cases per million state residents, our measure of efficiency of the state court system, and PCTDEMPR.

For the acids regression, ξ is equal to 4.71, which falls in the rejection region of the chi square with one degree of freedom, whereas for the ammonia regression ξ is equal to 1.488, leading us to conclude that liability is not endogenous with ammonia spill events. Based on these mixed results, for the purposes of this paper we keep the lagged strict liability indicator among the independent variables of the spills equations, and leave further investigation of the endogeneity problem for future research.

[29] Benefits should, therefore, depend on the number of people exposed; the quantity (volume) of toxic substance released; the (dollar) value of a statistical life, or the average willingness to pay to avoid the symptoms caused by exposure to the toxic release. Of these factors, quantity released is likely to depend on firms' underlying propensity to experience releases of pollutants and their response to the liability regime.

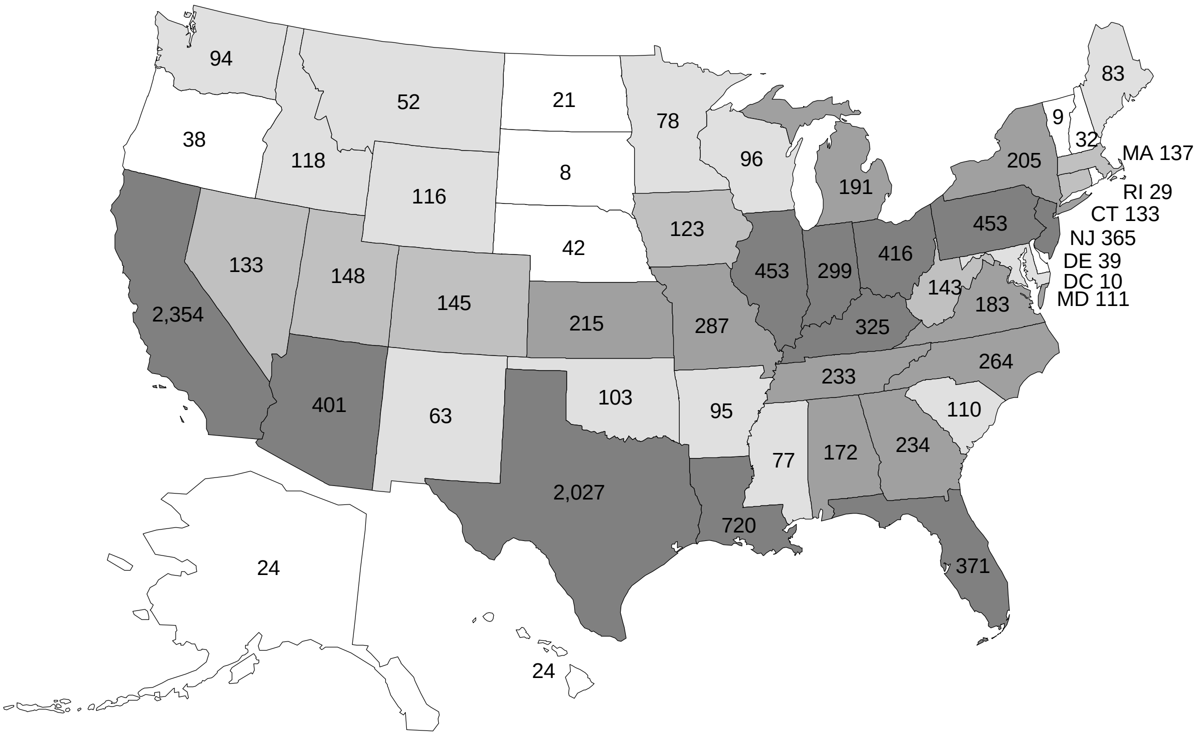

Figure 1: Total Number of Acid Spills, 1987-1995

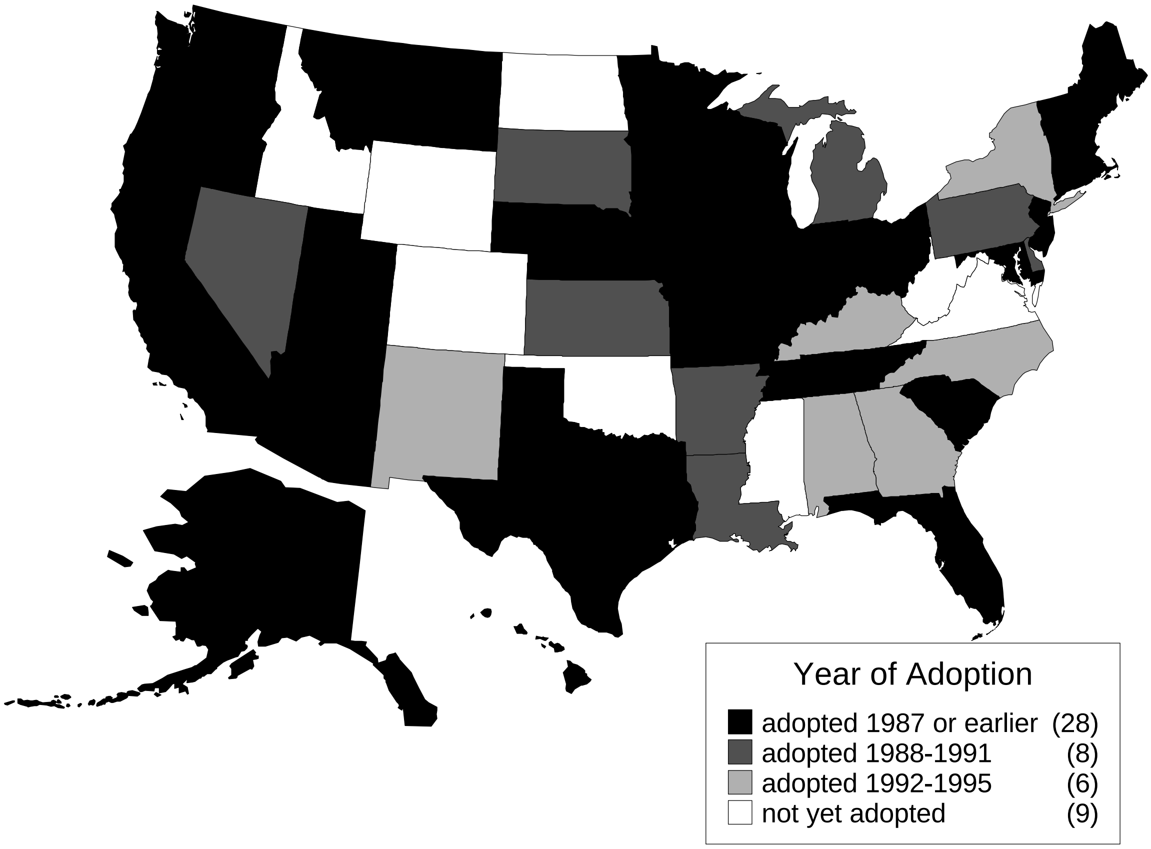

Figure 2: State Adoption of Strict Liability