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

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Abstract

This paper explores the issue of whether strict liability imposed on polluters has served to reduce uncontrolled releases of toxics into the environment. Strict liability should create additional incentives for firms to handle hazardous substances more carefully, thus reducing the future likelihood of uncontrolled releases of toxics. However, the size of these incentives may vary according to the size of a firm's assets, since asset size is the ultimate limit on a firm's liability. We are therefore interested to see whether imposing strict liability for the cost of remediation at hazardous waste sites has encouraged firms to handle toxic materials more carefully and has uniformly reduced the incidence of toxic spills, or whether the effect is dependent on firm size and other factors.

To answer these questions, 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 coming from a comprehensive database of events reported to the US EPA under their Emergency Response Notification System (ERNS), and fit 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), we find that the impacts of manufacturing activities on the number of spills in each state *do* vary systematically with the liability regime. In particular, it appears that under strict liability small firms are responsible for a disproportionate number of spills. Since strict liability states tend to have more manufacturing firms, and more *small* manufacturing firms, these factors serve to *increase* the number of spills of these chemicals in strict liability states.

Key Words: strict liability, hazardous substances, accident risk

JEL Classification Nos.: L51, K32, D21

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STRICT LIABILITY AS A DETERRENT IN TOXIC WASTE MANAGEMENT: EMPIRICAL EVIDENCE FROM ACCIDENT AND SPILL DATA

Anna Alberini and David H. Austin[1]

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. For instance, the federal program commonly known as Superfund (CERCLA, 1980; re-authorized in 1986 and further extended in 1991[2]) and the hazardous waste cleanup laws of many states hold those parties that have contributed to forming high-risk hazardous waste sites liable for the costs of cleanup. Similarly, the Offshore Continental Shelf Act (1974) imposes strict liability on oil companies for damages from off-shore spills occurring during drilling operations, and requires use of the best available technologies to ensure safe drilling.

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). Shavell (1984) specifically considers small firms in comparing probabilities of accidental releases under strict liability and under an alternative regime based on a negligence standard, discussing the conditions under which one of these liability regimes may be preferred to the other. Beard (1990) and 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.

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[2] 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 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.

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.[3]

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 ñ including waste generators and transporters, and operators of waste sites ñ are held responsible for any cleanup costs at high-risk toxic waste sites, without requiring proof they acted negligently or with intent (Fogleman, 1992).[4] 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).[5] 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

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[3] Ringleb and Wiggins (1990) deal with occupational safety. They find that entry of small manufacturing companies has been particularly pronounced into industrial sectors with high potential liability for workers' long-term health effects from toxic exposures. This suggests that regulations, dating from the 1970s, that make firms liable for such adverse health effects have resulted in large companies delegating operations bearing toxics risks to smaller, judgment-proof companies.

[4] 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.

[5] 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.

accidental events, above and beyond that of the federal Superfund. In particular, we care 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.

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), we find that the impacts of manufacturing activities on the number of spills in each state *do* vary systematically with the liability regime. In particular, it appears that under strict liability small firms are responsible for a larger share of spills**.** Since strict liability states tend to have more manufacturing firms and more small manufacturing firms, these factors serve to *increase* the number of spills of these chemicals in strict liability states.

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; the econometric model, the variables and the regression strategy are presented in Section 5; and Sections 6 and 7 present the results and conclusions.

2. THEORETICAL CONSIDERATIONS

In this section, we examine the models of Shavell (1984), Beard (1990) and Larson (1996) to establish the determinants of firms' optimal levels of care against uncontrolled releases of pollutants into the environment, and to provide a framework for our empirical work.

Shavell (1984) considers a firm that, at some cost *x*, can reduce its likelihood of an accident. When an accident occurs, damages are $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, a 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. Liability can be superior to a negligence standard when either 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.

To summarize, imposing strict liability has the potential to change the level of care taken by a firm relative to a negligence standard -- and hence the probability of an accident.

The size of the change should depend on firms' total potential liability, D;[6] on the wealth of the firm, W; on the probability of a suit, *p;* and on regulator's ability, absent strict liability provisions, to appropriately set the negligence standard, which in turn depends on the variation of D across firms. Formally, the difference in accident probabilities between the two liability regimes is given by:

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

where P_I denotes the probability of an accidental release of toxics under regime *I*, $I \in$ {N(egligence), S(trict)}, and s(D) measures the variation in D across firms. Equation (1) informs our empirical analyses by suggesting that in addition to *I*, we must control for W, D, s(D), and p. Shavell argues that $(P_N - P_S)$ is an increasing function of (W-D), s(D), and *p*. This suggests, in particular, that for given levels of s(D) and *p*, small (large) firms -- for which W-D is more likely negative (positive) -- may take a greater level of care under a negligence standard (strict liability).

Other models, such as those developed by Beard (1990) and Larson (1996), do not necessarily support this hypothesis. Beard (1990) 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 (1996) 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).

Together, the Beard and Larson models suggest that whether the liability regime and other factors increase or decrease the likelihood of accidents remains an empirical issue, and that no prior expectations can be formed on the direction of the effects of W, I, s(D), and D on the likelihood of accidental events. It is, indeed, this empirical issue that we explore in this paper. To examine how toxic spill rates respond to the incentives created by strict liability, we focus on sudden and accidental releases occurring over a relatively recent time period.

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

3. THE SPILL AND ACCIDENT DATA

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, and use state-level variables in proxying for D, s(D), W, and *p* as predictors of the number of spills.[7] 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 place where each discharge occurred, identifies the nature of the substance spilled, the statute under which the release was reported, the medium into which the substance was released (air, soil, water, groundwater), and specifies whether the accident occurred during transportation or within a facility. It also attempts to identify the cause of the accident (natural phenomenon, operator error, equipment failure, etc.) and to 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 models of the *quantity* of chemicals released. 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

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[7] Given our interest in policies that address toxic waste sites, another way of examining the outcome of imposing liability could be to focus on the number of hazardous waste sites listed under the federal or state programs. We opted against doing so for two reasons. First, many such sites are the result of disposal practices of the past, and do not reflect current incentives. Second, the discovery of such hazardous waste sites and their placement on priority lists depends crucially on the state or federal enforcement activity, while here we wish to focus on firm behaviors.

[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 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 adjoining shoreline; or (3) causes a sludge or an emulsion to be deposited beneath the surface of the water or upon the adjoining shoreline.

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.

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. These patterns 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 the appendix for descriptions of these chemicals, their properties and uses, and their effects on human health.)

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 firm's facility (70 percent),[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 percent to 38 percent, with the remainder distributed 12 percent in water, 2.8 percent in groundwater, and 1.6 percent 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

[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).

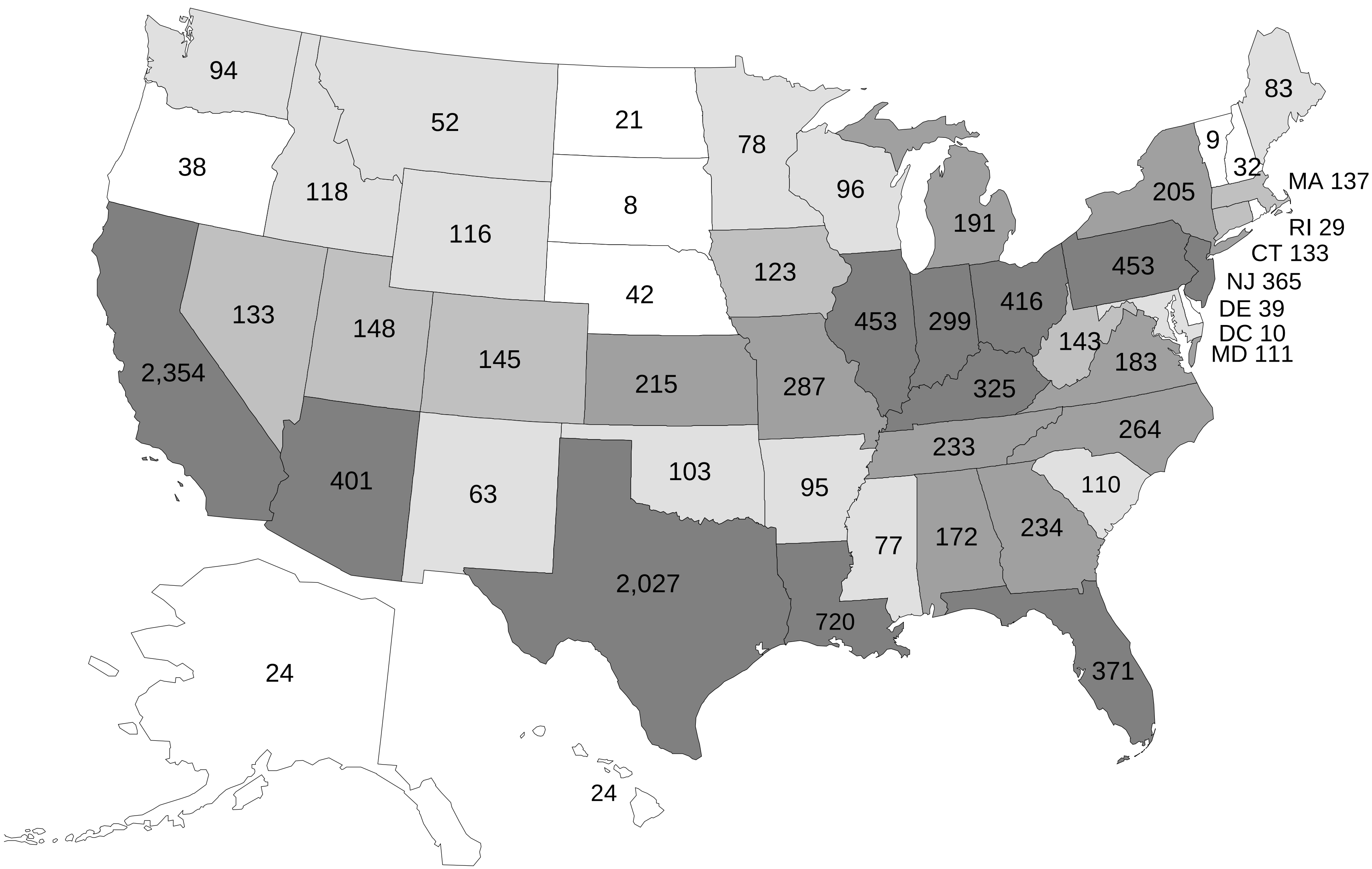

Figure 1. Total Number of Acid Spills, 1987-1995

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.

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 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. 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 ñ acids and ammonia ñ we use an OLS regression model. For the other families with fewer spills, we use a Poisson model.

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[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.

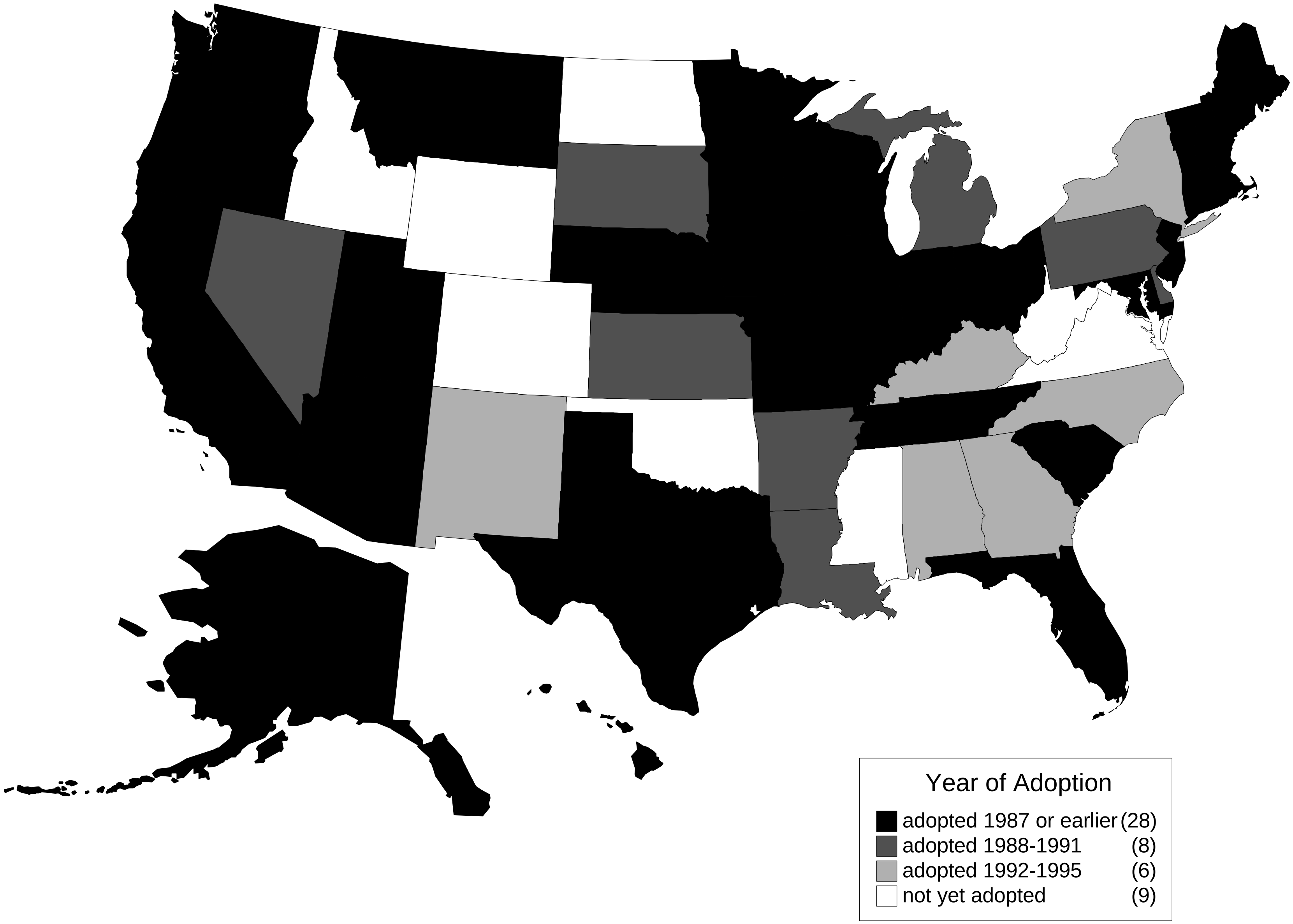

Figure 2. States' Adoption of Strict Liability

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

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

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). These 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). β is a vector of parameters. 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 descriptive statistics of the data in Table 1). The data contain many more zero counts (states with 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:

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

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

The number of toxic spills should depend on the extent of economic activity relying on chemicals. We capture this, and the breakdown of industrial activity into wealthy and less wealthy firms, by using 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.[11] 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 capture damages D, which are not observed directly, we create a pair of indicator variables, VICTCOMP and PUNDAMAGE, for, respectively, the presence of provisions for

[11] 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.

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

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

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 in practice, 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, with the result that there may be more ñ or more severe ñ spills. Of course, theory suggests the effect may work in the other direction, and it is left to empirical work to reveal its actual effect.

We lag the dummy variables STRICT, CITSUIT, VICTCOMP, PUNDAMAG one year in hopes of avoiding possible endogeneity with the dependent variable (number of spills), and to account for the lag, if any, in firms' behavioral responses to new laws.

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: population density (accidents may be more difficult to conceal in highly populated places), and membership, per 1000 residents, in either of three major environmental organizations (environmental awareness of the population may affect the level of scrutiny and reporting). Population density may also influence the extent, and hence the cost, of cleanup. Finally, we include among the regressors the amount of hazardous waste per capita generated in the state.

For both the OLS 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 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.

After establishing these relationships, we attempt to control for the *composition* of manufacturing in each state over several key industrial sectors. To see if behavioral responses of firms are structurally different under the two alternative liability regimes, we then run separate regressions for states and years with and without strict liability.

6. RESULTS

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

Table 2. Spills in fixed facilities: Basic specifications

Variable	OLS Acids. Dep. Var.: log(count+1)		OLS Ammonia Dep. Var.: log(count+1)		Poisson Chlorine Dep. Var.: count		Poisson Halogenated Solvents Dep. Var.: count		Poisson TCA, TCE, METH, PERC Dep. Var.: count	
	A	B	A	B	A	B	A	B	A	B
intercept	-2.0326 (-4.538)	-1.7198 (-3.805)	-4.0800 (-7.584)	-3.6768 (-7.048)	-5.0640 (-5.964)	-5.1263 (-19.668)	-4.2179 (-4.350)	-4.5603 (-2.669)	-6.8166 (-8.184)	-6.1816 (-8.801)
log manuf. Firms	0.2908 (5.260)		0.6872 (13.825)		0.7220 (9.244)		0.7463 (8.558)		0.8564 (11.268)	
log mining firms	0.4266 (10.421)									
log manufact. firms 20+		-0.2766 (-1.841)		0.2106 (1.125)		-0.8101 (-8.628)		0.1575 (0.395)		0.4691 (1.666)
log manufact. firms < 20		0.5975 (3.585)		0.4792 (2.398)		1.5596 (15.854)		0.7071 (1.557)		0.3823 (1.411)
log mining firms 20+		0.3214 (4.515)								
log mining firms < 20		0.1082 (1.491)								
hazwaste	0.0220 (1.635)	0.0100 (0.687)	0.0440 (2.659)	0.0440 (2.632)	0.1178 (7.750)	0.1219 (8.524)	0.0738 (2.988)	0.0731 (3.008)	0.0507 (2.573)	0.0495 (2.492)
log pop. Density	-0.0246 (-2.070)	-0.0269 (-2.004)	-0.2078 (-4.823)	-0.2111 (-4.168)	-0.0129 (-2.543)	-0.0013 (-0.046)	-0.0717 (-1.094)	0.1073 (0.822)	0.1224 (1.835)	0.0960 (1.209)
ENVORG	0.1922 (4.789)	0.2446 (5.474)	-0.0865 (-5.962)	-0.0864 (-5.579)	-0.0803 (-4.000)	-0.0970 (-11.011)	-0.1377 (-5.025)	-0.1548 (-2.871)	0.0037 (0.176)	0.0078 (0.325)
strict (lagged)	0.3564 (4.182)	0.4408 (5.214)	0.3161 (3.065)	0.3138 (3.008)	0.7216 (6.346)	0.7392 (12.706)	0.4576 (4.486)	0.2631 (0.547)	0.5540 (3.750)	0.5392 (3.529)
citizen suit (lagged)	0.2314 (3.120)	-0.2475 (-2.503)	0.2464 (2.248)	0.2568 (2.246)	0.3314 (2.488)	0.4066 (9.208)	0.3383 (2.336)	0.7798 (1.914)	0.2715 (2.100)	0.2625 (1.941)
punitive damages (lagged)	-0.0392 (-0.462)	-0.0744 (-0.866)	0.1970 (1.862)	0.1986 (1.830)	-0.0898 (-0.683)	-0.1982 (-4.186)	0.0318 (0.268)	-0.2843 (-1.690)	-0.4337 (-3.198)	-0.4124 (-2.912)
victim compens. (lagged)	-0.1480 (-1.563)	0.2692 (3.711)	0.2577 (2.160)	0.2568 (2.099)	0.1665 (1.520)	-0.0998 (-0.557)	0.1636 (1.536)	-0.3088 (-1.518)	-0.5578 (4.743)	-0.5205 (-4.089)
adj. R^2	0.6423	0.6649	0.4675	0.4684						
F statistic	78.997	70.252	43.904	39.281						
Log Likelihood					-3303.03	-3366.59	-3161.45	-2216.34	-250.13	-251.23
n	392	384	392	392	391	391	391	392	392	392

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

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 47 and 66 percent, respectively. The coefficients of the logs of total mining and manufacturing firms (column A for each chemical family) are positive but less than one, implying that, *ceteris paribus,* the number of spills increases with the number of establishments, but at a decreasing rate.[12]

Looking at 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 that adopt strict liability continue to have higher rates of toxic spills. This finding persists even after we account for the numbers of small production units in a state (regressions B), allowing small firms to experience spills at a different rate than larger firms.

This finding is robust across different chemical families and specifications: states with strict liability policies generally have 30 to 70 percent more spills than states maintaining negligence-based liability standards, above and beyond what is predicted by the level of economic activity in the state and by the relative numbers of smaller and larger establishments operating there.[13]

Excluding the dummy variables that capture other aspects of the state programs generally does not change the results on strict liability, or their statistical significance. The effects of other attributes of the state programs appear to vary with the specification and with the chemical being analyzed: the presence of punitive damages provisions, for instance, is not a significant determinant of the number of spills involving acids, but has a strong, negative effect on the number of spills of TCA, TCE, METH and PERC.

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 B of Table 2, the coefficients of large firms are equal to their small-firm counterparts.

We obtained mixed results: the null hypothesis of equal small- and large-firm effects is *rejected* 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. The contributions of small and large firms to the frequency of ammonia spills and of the subset of four halogenated solvents is not statistically different.

The effect of population density is *negative* for almost all specifications and chemicals, while the coefficient of membership in leading environmental organizations

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[12] 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). If the Poisson model is misspecified, V and F can be quite different.

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

frequently switches sign from one regression to the next. It is certainly possible that plants located in areas with higher population density feel compelled to exercise care in avoiding accidents, for fear that accidents will be noticed, reported, and will be expensive to clean up. However, we worry that the signs of these effects might be the result of the moderate, but significant, correlation between these variables.

The quantity of hazardous waste generated per resident is also significantly, positively related to the frequency of spills, in all but the acids regression. 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 really not very large.

Interpreting Results

That the presence of strict liability is a positive and significant predictor of spills, even after controlling for the presence of small production units, is consistent with several possible explanations.

First, the effect could be real ñ 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 correlated with both the number of spills and the adoption of strict liability law. We leave this explanation to future research.

Third, the presence of strict liability may have caused the relocation of certain *types* of production operations that tend to result in a larger number of spills. This might be the effect if adoption of strict liability were to cause larger firms to migrate out of state or to spin off small, more "judgement-proof" subsidiaries to handle their risky lines of business in-state. Data limitations, unfortunately, prevent us from accounting for particular production processes.

Fourth, 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. Finally (fifth) 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 major variables in the model (not only firm and state size variables, but also the other characteristics of states' cleanup programs) differ across states that do and do not have strict liability provisions, imposing that they be equal may result in biased estimates.

To discriminate between the third, fourth, and fifth explanations, we begin by controlling more carefully for the composition of manufacturing within a state, checking whether this changes the sign, magnitude, and significance of the strict liability effect.

Formal testing of the fourth and fifth 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. Rejecting this null hypothesis would imply that at least part of the differences in spills rate between the two liability regimes are due to reporting effects.

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.

Composition of Manufacturing

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 logs of the numbers of plants in 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.[14] 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.

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. We examined various explanations for this finding. One explanation is that the presence of other environmental regulations overwhelms the incentives posed by liability. But when we included state regulations and standards for emissions of halogenated solvents (reported in Sigman, 1996), we found no evidence of a significant correlation with the number of spills involving these substances. Other provisions of the state program (victim compensation and punitive damages) appear still to be associated with a lower number of spills.[15, 16]

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 in our next analyses.

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[14] 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.

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

[16] 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.

Table 3. Spills in fixed facilities: Composition of manufacturing

	OLS	Poisson	Poisson	Poisson
Variable	**Anhydrous Ammonia**	**Chlorine**	**Chlorinated 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)
ENVORG	-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.

Reporting Effect and Structural Change

In Table 4 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.

The null hypothesis of equal propensities to report spills in states and years with and without strict liability implies the equality of the coefficients on population density and environmental awareness.[17] The Wald test clearly rejects this null hypothesis, although it is difficult to identify a pattern for the sign and significance of the two reporting variables across the chemical families.

The table also displays the results of the Wald test of the hypothesis about firm size. For each of chemical family, the Wald test rejects the null hypothesis that the coefficients of small and of large plants, in logarithm form, are the same across the two liability regimes. Indeed, the estimation results show clearly that, in strict liability regimes and holding all else unchanged, variation in the number of spills is explained by variation in the number of *smaller* plants (the more small plants, the more spills). 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 in the ammonia and chlorine regressions, neither firm-size variable is a significant predictor of the number of spills.

These estimated equations 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.)[18]

Accordingly, taking these differences into account, the two separate regression equations in Table 4 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. 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

[17] 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.

[18] 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 ñ rising from 67 percent to 70 percent even as almost half the states adopted strict liability.

Table 4. 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 regressions: misspecification-consistent t statistics.

Wald test on reporting variables tests 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 percent significance level, the critical value is 5.99.

similar results. We conclude that *differences in the number of plants* and in *the higher propensity of small firms to experience spills* is what makes accidents 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 the signs we would expect from Shavell's model. 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. (In the pooled regressions of Table 2, their effects were uncertain ñ VICTLAG was usually *positive* and significant for acids and ammonia spills.) For instance, for acid spills in states with strict liability, we get the following estimated equations (t statistics in parentheses):

$$
\begin{array}{lllll}
\ln(\text{acid spills}+1) = \underset{(-6.701)}{-3.6070} & \underset{(2.065)}{+0.0993^{*}\,\text{lpopdens}} & \underset{(-4.615)}{-0.0752^{*}\text{envorg}} & \underset{(4.582)}{+0.1200^{*}\text{hazwaste}} & \\
\underset{(-2.419)}{-0.4623^{*}\ln(\text{LGMFG})} & \underset{(6.149)}{+1.2699^{*}\ln(\text{SMLMFG})} & \underset{(-1.917)}{-0.1955^{*}\text{pundlag}} & \underset{(0.835)}{+0.0825^{*}\text{citlag}} & \underset{(-2.098)}{-0.2472^{*}\text{victlag}}
\end{array}
\tag{4}
$$

In equation (4), 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, which is against expectations, but not statistically significant.

The corresponding regression for states and years *without* strict liability reveals that the effects of these variables are positive, but not statistically significant.

7. 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. 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 the other chemicals we have analyzed (acids, chlorine, and ammonia) our empirical evidence suggests 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 than states relying on negligence standards, this effect is magnified because there are more small firms in strict liability states as well.

The small-firm finding is consistent with the predictions of Shavell's theoretical model of firms' level of care, and 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.

In the presence of strict liability, other attributes of state cleanup programs that we believe capture the likelihood of being targeted by the state agency and the potential size of the damages *also* appear to affect the number of spills, in a way that is consistent with the predictions of Shavell's model. Specifically, in 'strict liability' states, state program attributes that increase firms' potential liabilities from spills (such as victim compensation provisions) or the likelihood of being targeted by the agency (such as citizen suit provisions) are associated with *fewer* spills and accidents. By contrast, these attributes do not have a discernible effect in states that have not adopted strict liability in toxics regulation.

To summarize, we have found evidence that strict liability *can* increase the frequency of accidental releases of toxic into the environment. Further research, hopefully 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.

APPENDIX: 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 percent 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 both 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 ground water 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. The decision of a social planner on how to allocate the use of methyl ethyl ketone so as to minimize current and future disposal costs, and the disutility of current and future disposal of this chemical into the environment, is examined by Eisworth (1993).

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