Accidents Waiting to Happen: Liability Policy and Toxic Pollution Releases

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Abstract

Proponents of environmental policies based on liability assert that strict liability imposed on the polluter will induce firms to handle hazardous wastes properly and to avoid disposing them into the environment. Economic theory and a few well-publicized cases, however, suggest that a number of factors may dilute the incentives posed by strict liability.

In this paper, we run regressions relating unintended releases of pollution into the environment (aggregated at the state level, and followed over nine years from 1987 to 1995) to the imposition of strict liability on the polluter, exploiting variation across states in the liability provisions of their mini-Superfund laws, and in the years these were adopted.

We experiment with instrumental variable estimation, fixed effects, and endogenous switching, and find that only after we explicitly model the endogeneity of states' liability laws is strict liability seen as reducing the seriousness of spills and releases. We also find evidence consistent with the notion that under strict liability, firms may spin off into, or delegate riskier production processes to, smaller firms, which are partially sheltered from liability. This tendency appears to be widespread.

Key Words: strict liability, toxic spills, policy endogeneity

JEL Classification Numbers: Q28, C33, K32

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1. INTRODUCTION

This paper examines whether imposing strict liability for the cost of cleaning up contaminated sites has increased the level of care taken by firms to avoid uncontrolled releases of pollutants into the environment, and reduced the severity of such events.

Proponents of environmental policies based on strict liability contend that, faced with the prospect of disbursements over cleanup or to compensate third parties, firms will avoid improper disposal of pollution into the environment. In practice, a number of US environmental statutes incorporate strict liability for polluters. Under the Comprehensive Environmental Response, Liability and Compensation Act (CERCLA, originally passed in 1980), parties that have contributed to badly contaminated sites may be forced to undertake remediation, or to pay for cleanup initiated by the Environmental Protection Agency. The full burden of environmental costs is placed on the responsible party (the polluter) and the EPA does not have to prove that the party failed to meet a standard of due care. Strict liability is often imposed on polluters by state "mini-Superfund" laws, which address the numerous non-priority hazardous waste sites that do not qualify for the federal Superfund program, and by the Continental Shelf Offshore Continental Shelf Act (1974), which deals with damages from off-shore spills occurring during drilling operations.

Legal liability is one way in which firms can be made to internalize the pollution damages associated with their production activities (Hanley et al., 1997), and is a potentially powerful tool for addressing pollution problems (Tietenberg, 1989). It is an *ex post* type of intervention, and has the advantage of giving firms flexibility in how they wish to reduce the likelihood of uncontrolled releases of pollutants, while relieving the government from having to devise and prescribe safety standards, and monitor firm compliance with regulations (Boyd, 1996).

However, several factors may dilute the incentives of legal liability. Firms with relatively limited assets may be sheltered from the economic incentives created by strict liability (Shavell, 1984; Tietenberg, 1989). 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 for the adverse health effects on workers exposed to carcinogens may have in fact

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encouraged wealthier firms to spin off into--or subcontract risky operations to--smaller, judgment-proof companies in hopes of avoiding liability. Anecdotal evidence suggests that firms may engage in similar behaviors in response to the imposition of liability for the cost of cleaning up contaminated sites, but we are not aware of any prior research to ascertain how widespread this phenomenon is.[1] Finally, the incentives created by liability can be altered by the availability and cost of pollution insurance.

In this paper, we empirically explore the effects of strict liability on uncontrolled releases of pollutants into the environment, exploiting differences across the states in the liability structure imposed by their "mini-Superfund" programs. These programs typically confer authority for the regulator to force responsible parties to conduct or pay for initial feasibility studies and remediation activities at non-priority sites, and establish financing mechanisms to pay for such activities when the responsible party is insolvent or no longer in existence (EPA, 1989). As of 1995, forty-five states had passed statutes providing for enforcement authority and funding mechanisms.

An important difference between the Federal Superfund program and many state programs lies in the liability standards imposed on the responsible parties: Liability under the federal Superfund is strict and joint-and-several, but this is not necessarily the case for many of the state programs. As of 1987, twenty-seven states had instituted strict liability; by 1995 this number had climbed to forty.[2] The remainder of the states relied on negligence-based liability.

Absent data on firms' expenditures on care, this paper uses data on accidents and spills involving hazardous substances to establish whether the severity of these spills has been systematically affected by the introduction of strict liability. The spill data come from a comprehensive database of events reported to the EPA under its Emergency Response Notification System (ERNS). Because ERNS was begun in 1987, we are unable to establish how the previous passage of the federal Superfund law affected accidental releases. Instead, we

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[1] A well-known example is Allied Chemical's 1973 decision to subcontract its production of the pesticide Kepone to a small company, Life Sciences Products. The firm was owned and run by two former Allied Chemical employees, and was to purchase raw materials from and sell Kepone to Allied Chemical. It was soon discovered that both Life Sciences and Allied Chemical were illegally discharging Kepone in the James River, and that Kepone dust covered the floor of the Life Sciences plant and contaminated its indoor air. Air emissions from the plant occasionally halted the traffic in the surrounding neighborhood, and irritated the skin and eyes of the employees of a nearby ice distribution plant. The EPA determined in 1975 that the Life Sciences plant should be dismantled and its site decontaminated, and assessed Life Sciences a fine of $3.8 million. The fine was never paid, since at the time of the assessment the firm was only worth $32 (Wentz, 1989). Boyd (1996) cites another example of how the option of declaring bankruptcy is always available to firms. A 1989 fish kill in Virginia alerted state officials of widespread contamination originating from the Kim-Stan landfill. The facility was charged fines of $1.5 million, but filed for bankruptcy and ended up paying only $100,000.

[2] States' liability structures have often changed over time. Although the trend is towards adoption of strict liability, a few states that had previously adopted strict liability repealed it in 1995. Thirty-four of the states imposing strict liability also impose joint-and-several liability. In addition, 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 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.

examine whether the strict liability feature of state cleanup programs has had any *additional* influence on the severity of accidental events, above and beyond that of the federal Superfund.

Since this paper exploits the variation in liability regimes across states and over time, this research is an example of a "natural experiment": variation in the presence and/or level of policies across locations and time is used to test whether a policy has attained its objectives or created perverse effects, and to estimate the magnitude of such effects.

Earlier "natural experiment" analyses have typically developed regression models where the presence and/or level of the policy is included among the regressors. Besley and Case (1994) have recently questioned whether such procedures are appropriate, arguing that the estimated coefficient of the policy variable is biased (and inference about the effects of the policy invalid) if the policy and the outcome of interest are endogenous.

Important environmental policies that may be endogenous with their outcomes include those addressing hazardous waste management and prevention of contamination at hazardous waste sites. Levinson (1997) shows that states that impose high taxes on the disposal of hazardous waste seemingly attract large volumes of such wastes from other states--a finding that goes against economic theory. Once the endogenous nature of waste-end taxes is recognized and handled through instrumental variable estimation, the coefficient of the waste-end tax rate becomes negative and significant. This suggests that states that have traditionally received large amounts of hazardous waste impose high waste-end taxes in hopes of discouraging imports of hazardous waste, and are generally attaining this goal.

By contrast, Sigman (1998) finds that states requiring the recycling and reuse of waste oil have more numerous instances of illegal dumping of used oil. She concludes that making reuse of waste oil mandatory has raised its cost of disposal, encouraging "midnight dumping." However, this empirical finding is also compatible with an alternative explanation: that states have enacted reuse requirements *because* they had improper disposal problems to begin with.

Prompted by such considerations, in this paper we estimate Poisson regressions relating the severity of chemical spills to the extent of manufacturing activity and hazardous waste generation in the state, and the liability structure of the state's mini-Superfund program. We develop a two stage, instrumental variable approach, motivated by a simple model of state policy choice, to accommodate the endogeneity of the liability policy and spill outcomes. In our analysis, we compare our two-stage estimation results with estimates we get from a (single-stage) regression allowing for state-specific unobserved heterogeneity, and a two-stage model allowing for structural change across alternative liability regimes.

We find that states with more serious spills *are* more likely to adopt strict liability, and this policy *does* afford them a reduction in spill severity over time. We also find evidence consistent with different behavioral responses by large and small firms, the latter being partially sheltered from liability.

Our analysis of severe spills complements results reported by Alberini and Austin (1998). There it was shown that states adopting strict liability policies had higher rates of spills and accidents, and continued to experience elevated rates--relative to other states with similar levels and types of industrial activity--after the adoption of strict liability. This result may have been due to behavioral differences between small and large firms. The state's decision to adopt strict liability was not explicitly modeled in that paper.

The remainder of the paper is organized as follows. In section 2, we summarize the theoretical results about the effects of strict liability and present a simple model of state adoption of strict liability within its hazardous waste cleanup legislation. Section 3 presents the econometric model and the data, and section 4 discusses the independent variables of the econometric model. Section 5 presents the results, and section 6 concludes.

2. A STATE'S CHOICE OF LIABILITY STRUCTURE

State legislatures may decide between strict liability and a negligence standard in the belief that their choice will influence the occurrence and/or severity of toxic releases.

Economic theory suggests that firms can, in most cases, be expected to respond to the imposition of liability by changing their investment in accident prevention and safety equipment. The extent of this response, however, depends on firms' assets relative to their potential liability exposure, liability regime and standards of due care, the likelihood of prosecution by the state agency, the availability and cost of pollution insurance, and on the existence of safety devices and technologies.

Under ideal conditions, firms held strictly liable for pollution damages will undertake the socially efficient level of care (Shavell, 1984).[3] If the harm caused by a firm exceeds its assets, or if the firm can escape legal judgement, the level of care chosen by the firm will be less than the efficient level. With damages of uncertain size, however, it remains unclear whether the level of care rises with the assets of the firm: large and wealthy firms may or may not be safer than smaller firms (Beard, 1990). Whether strict liability or negligence-based liability is more effective at inducing efficient care against spills depends on how stringent the negligence standard is (at least when the firm's assets are sufficient to pay for the damages; Tietenberg, 1989).[4]

Although it will be difficult, in general, to predict the *aggregate* level of pollution releases in a state, a rational state legislature should enact the liability regime that maximizes

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[3] Shavell (1984) assumes that a firm faces a probability p of incurring an accident resulting in damages $D. The amount D is known and fixed for a firm, but it may vary across firms. The firm's precautions to reduce this probability are a function of its expenditures e to take care: p=p(e), where $p'(e)<0$ and $p''(e)>0$. Under strict liability, the firm must compensate victims for the damages, which makes the firm's private expected costs (the sum of precaution costs and expected damages) equal to social costs: $e+p(e)\cdot D$. The firm chooses e^* such that its marginal cost is equal to the marginal benefit of care (the reduction in its expected payments to victims). Assuming that the firm has assets sufficient to compensate victims in the event of an accident, and that it cannot escape suit, the firm's choice of care e^* is also the socially optimal level of care.

[4] Tietenberg (1989) shows that under negligence-based liability firms will typically adopt the court-prescribed standard of due care, $\tilde{e}$, since as long as e exceeds or is equal to the standard $\tilde{e}$, the firm's sole spill-related expense would be the cost of taking care. The only exception is if $\tilde{e}$ is greater than the expected cost incurred by the firm under strict liability, or $e^*+p(e^*)\cdot D$. In that case, the firm chooses a level of precaution equal to e^*.

the net benefits of the state's hazardous waste cleanup program.[5] We assume that benefits are the reduction in expected health damages for the population exposed to accidental toxic releases at contaminated sites where mitigation is subsequently undertaken. Formally,

$$B = \Delta r \cdot N(\mathbf{Z}) \cdot Q(E(S,\mathbf{A};\mathbf{Z});\mathbf{Z}) \cdot V(\mathbf{Z}) \quad (1)$$

where Δr is the mitigation-induced change in the risk of developing health problems, such as cancer or acute symptoms, per person exposed, per unit of volume of the toxic substance. N is the number of exposed persons; Q is the quantity (volume) of toxic substance released; and V is the (dollar) value of a statistical life, or the average willingness to pay to avoid the symptoms of exposure to the toxic release.

Q should depend on the type and composition of economic activity in the state, **Z**, reflecting the underlying propensity to release pollutants. It should also depend on the expenditure E incurred by firms to install safety equipment and monitor operations more closely to avoid pollution releases. E is assumed to depend on the presence of strict liability (S; S=0,1), other liability and program attributes--here summarized into the vector **A**--and firm characteristics (contained in **Z**).

The size of the exposed population should be influenced by residential patterns and population density, whereas the value of a statistical life used in the state's net benefit calculus should depend on socioeconomic characteristics and residents' tastes. The vector **Z** therefore includes variables such as income and education (see Tolley et al., 1994) along with economic activity variables.

The costs of the program include the litigation and administrative costs of forcing responsible parties to mitigate, plus any unrecoverable cleanup costs borne by the state. The state's costs are assumed to be proportional to the quantity released:

$$C = a(S,\mathbf{A};\mathbf{Z}) \cdot Q(E(S,\mathbf{A};\mathbf{Z});\mathbf{Z}) + p(S,\mathbf{A};\mathbf{Z}) \cdot c(\mathbf{Z}) \cdot Q(E(S,\mathbf{A};\mathbf{Z});\mathbf{Z}) \quad (2)$$

where a is the average administrative and litigation cost per unit of volume of the chemical, p denotes the fraction of all mitigation costs which the state must absorb, and c is the average total cost of mitigation per unit of volume released.

Administrative and litigation costs, a, are likely to vary with the type of liability adopted within the state program, as well as with the resources available to the state agency in charge of the mini-superfund program.

By its choice of liability structure and other program attributes, the agency can influence the probability p that the state will have to absorb unrecovered costs. However, its ability to control p may be affected by firm wealth: A state with a prevalence of small firms,

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[5] Earlier literature that has assumed and empirically tested that government agencies act rationally when developing environmental regulations (or making cleanup decisions at Superfund sites) include Magat et al. (1986), who examine the stringency of allowable effluent levels as per the Clean Water Act; Cropper et al. (1992), who model the decision to cancel or register pesticides; and Gupta et al., (1996), who identify determinants of cleanup strategies at individual Superfund sites.

for instance, may not find strict liability particularly useful, as such firms are more likely to have resources insufficient to handle the full costs of cleanup at their sites. By contrast, a state with an abundance of larger and wealthier firms may be able to keep $a(\bullet)$ and $p(\bullet)$ low by instituting strict and/or joint-and-several liability provisions.[6] The state legislature may also opt for strict liability if it believes it is objectively difficult for the regulator to establish a standard of negligence, and/or to determine when it has been breached.

In our stylized model, the net benefits of the liability system are thus equal to:

$$BC \equiv (B - C) = Q(E(S, \mathbf{A}; \mathbf{Z}); \mathbf{Z}) \cdot [\Delta r \cdot N(\mathbf{Z}) \cdot V(\mathbf{Z}) - a(S, \mathbf{A}; \mathbf{Z}) - p(S, \mathbf{A}; \mathbf{Z}) \cdot c(\mathbf{Z})] . \quad (3)$$

The state will select the type of liability *S* and other liability and program attributes, **A**, to maximize the net benefits of the program, subject to a resource constraint.[7] The optimal levels of liability policy *S* and other program attributes **A** should, therefore, depend on socio-economic characteristics **Z**, as should net benefits, firms' expenditure on safety, E^*, and total releases, Q^*, anticipated by the state. In this model, E^* and Q^* are endogenous with the liability structure of the program.

3. THE ECONOMETRIC MODEL AND THE DATA

Our theoretical model of state legislature behavior presumes that the state chooses the liability structure to influence the precautions *E* taken by firms against pollution, and hence, *Q*, the uncontrolled releases of pollution into the environment. A*ctual* releases, Q', may or may not be close to the level Q^* anticipated by the state, depending on the accuracy of the state's beliefs about the firms' behavioral responses and choices of *E*. Do states with strict liability have a lower level of Q', relative to states with comparable manufacturing, mining and population characteristics, but a different liability regime?

To answer this question, in this paper we estimate econometric equations for pollution releases, which we measure as the severity of spills and accidents involving toxic chemicals, expressed as the number of spill-related injuries.[8] Effectively, we examine $r_0 \cdot Q' \cdot N$ (where r_0 is the pre-mitigation risk of acute health effects).[9]

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[6] Once such provisions are incorporated in the law, at sites where more than one party has contributed to the releases it is in the state's best interest to target only a few parties (typically, deep-pocket firms) from which to collect the entire amount of the damages.

[7] The state's objective function can be modified to allow for pressure from interest groups resulting in different weights being given to certain component of costs and benefits. Alternatively, the state may consider the resources used in abating pollution, and focus on minimizing (B-(C+E)).

[8] We focus on accidental chemical spills for three reasons. First, data on E, expenditures on safety, are not publicly available. Second, chemical spills have the potential of triggering the federal and state Superfund statutes. Third, using chemical spills avoids the problems associated with examining contaminated waste sites recently listed on the federal or state priority lists, which may be the result of manufacturing activity many years ago, as opposed to the response to the current liability incentives.

[9] In Alberini and Austin (1998), the focus is on the frequency of releases, and spills of different chemicals are analyzed separately.

A. The Data

Our data come from the Emergency Response Notification System (ERNS) database compiled by the EPA in collaboration with the Department of Transportation.[10] For each spill or release of a toxic substance, the ERNS database reports the date and place where each discharge occurred, the substance spilled, the statute under which the release was reported, and the affected medium (e.g., air), specifying whether the accident occurred during transportation or within a facility. 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.

In theory, the ERNS database reports the quantity of chemicals released in each spill event. In practice, however, the quantity-released variable has many missing and zero values. It remains unclear whether zero is an alternative coding for a missing value (i.e., no information is available as to the quantity of chemicals released), or indicates a reported event in which only traces of the chemicals were actually dispersed into the environment.[11]

For this reason, we choose to approximate the severity of spills with their physical damages to human health, rather than with quantity released. The dependent variable in our econometric equation is, therefore, the total number of persons injured in chemical spills per state per year (from 1987 to 1995).[12] We include in our counts only the spills and accidents involving CERCLA-listed substances, and occurring at a plant, as opposed to offshore or during transportation. We do this to avoid the complexity of the federal, state and local regulations affecting chemical transport (Wentz, 1989).

The spills data were merged with manufacturing, mining and population variables (from assorted sources), and variables describing the liability structure in the state and its evolution over time (EPA, 1989, 1990, 1991; ELI, 1993, 1995). This produced a panel data set following the 50 states plus the District of Columbia for 9 years (1987-1995).

B. Spill Severity Equation

Since chemical-spill injuries are relatively rare events, we fit Poisson regressions assuming that state *i's* probability of experiencing *y* injuries in year *t* is:

$$\Pr(Y_{it} = y_{it}) = \frac{e^{-\lambda_{it}} \lambda_{it}^{y_{it}}}{y_{it}!} \qquad (4)$$

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10 See Alberini and Austin (1998) for reporting requirements and criteria.

11 Sigman (1998) reports a similar problem with used-oil dumping incidents, also documented in ERNS. When she examines the subset of spills for which quantity-released information is available (only about 42 percent of all incidents), she finds that the quantity released is not very sensitive to the stringency of state used-oil policies. It is possible that such finding is an artifact due to the non-representativeness of spills with quantity-released information.

12 We focus only on the acute health effects, due to our inability to document long-term effects of exposure. We analyze aggregate counts per state per year because the information reported in ERNS is in most cases insufficient to identify the party responsible for the spill, precluding individual-event or firm-level analyses.

where $\lambda_{it} = \exp(\mathbf{x}_{it}\beta + S_{it}\gamma + \mathbf{A}_{it}\delta)$, and that both the expected value and the variance of each dependent variable are equal to λ_{it}. The vector **x** contains state-level socio-economic variables, β is a vector of parameters, and *S* and **A** are a strict liability indicator and other associated policy variables, respectively.

To get a first feel for the data, we initially run Poisson regressions that include the liability policy variables in the right-hand side of the model. We include them to check if they explain the severity of spills beyond what is predicted by the extent and type of manufacturing and state socio-demographics.

It is clear that these initial regressions assume that the presence of strict liability is exogenous to the dependent variable. We subsequently relax this assumption and allow the strict liability variable to be endogenous with the dependent variable, first in fixed-effects models and then by using instrumental-variable estimation techniques.

C. Liability Structure Equation

If the liability structure within a state is endogenous with the spill outcome, it is necessary to specify an additional equation expressing (the probability of) adoption of strict liability as a function of a set of instruments. Once this additional equation is estimated, a two-stage procedure yielding a consistent estimate of γ is obtained by replacing *S* in the right-hand side of equation (5) with a state's *predicted probability* of adopting strict liability.

To build the equation explaining the presence or absence of strict liability adoption, we assume, as in section 2, that a state adopts the liability structure that maximizes the net benefits of its hazardous waste cleanup program. Net benefits are the value of the reduction in health risk after cleanup is completed, minus the state agency's cost of running the program.

We assume that the net benefits of regime *k* are expressed as:

$$NB_k = \mathbf{w}\alpha_k + \varepsilon_k, \qquad (5)$$

where the coefficients are allowed to vary with the liability structure ($k \in$ {S(trict), N(egligence)}), **w** is a set of variables influencing the state's benefit-cost calculus, and ε is a standard normal error term.

Because the net benefits of adoption of a liability regime are not observed, we cannot estimate (5) directly. What we do observe is whether the state mini-superfund program imposes strict or negligence-based liability. A state's adoption of strict liability, therefore, implies that it deems its expected net benefits to be greater than the net benefits from a program without that provision, leading to a probit equation.[13]

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[13] In reality, the state legislature does not pick the liability structure alone, but in concert with other liability and program attributes meant to influence firms' exposure to cleanup and damages claims. For example, the state may uphold joint-and-several liability, and impose punitive damages on recalcitrant firms. This suggests that k should really denote one of the many possible combinations of indicators and real-valued variables capturing liability and other attributes of the state's program, and that the appropriate econometric model is a multinomial logit model explaining the choice of one combination of attributes over all other possible combinations. However, Alberini and Austin (1999) show that a multinomial logit model explaining adoption of several liability attributes (strict v.

4. THE CHOICE OF INDEPENDENT VARIABLES AND INSTRUMENTS

A. Determinants of Spill Severity

The vector **x** in equation (4) includes state socioeconomic variables thought to influence aggregate spill rates and/or quantities released. Descriptive statistics for all variables are displayed in Table 1.

Table 1: Descriptive Statistics

Label (if used in later tables)	Description	mean	std. dev.
	Chemical-spill injuries per state per year	13.25	53.72
	number of mining establishments in the state	583.55	1091.20
	number of manufacturing establishments in the state	7143.69	8456.48
	number of manufacturing establishments with fewer than 20 employees in the state	4763.28	5747.49
	number of mining establishments with fewer than 20 employees in the state	466.80	912.28
EXPEND	state expenditure per capita (1987 dollars)	10096.00	11701.00
ENVPROG	percentage of state budget on environmental programs	1.86	1.19
SITES	suspected/actual hazardous waste sites in the state	1460.01	3821.68
LESSTHS	percent of adults 25 years and older that lack high school diploma	23.77	5.54
HIGHSCH	percent of adults 25 years and older whose highest educational attainment is completing high school	30.60	3.64
LPOPDENS	Log of population density (thou. residents per sq mi)	0.43	0.08
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
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
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
LAWYERS	Number of lawyers working on state mini-superfund cases per million state residents	1.38	1.73

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negligence-based liability; proportional v. joint-and-several liability; presence or absence of provisions authorizing punitive damages against recalcitrant responsible parties) can be collapsed to a simple binary model describing just the presence or absence of strict liability. The latent variable in our probit model is the difference between the net benefits of strict liability and those of the alternative regime. Strict liability is adopted if this difference is greater than zero. The coefficients of the probit model are the difference between the αs of the two regimes in equation (5).

The number of toxic spills and/or the quantities released should depend on the extent of economic activity involving chemicals. We capture this, and the distribution of industrial activity by firm size, using numbers of production units in the industrial and extractive sectors in the state, divided into "large" and "small" plants. Although both economic theory and actual examples emphasize that the incentives of liability may be diluted when firms' *assets* are limited, in our empirical work we are forced to proxy for firm size using numbers of employees to define small and large establishments. 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.[14]

Smaller and larger firms may contribute to pollution releases at a different rate for various reasons. On the one hand, firms with limited assets, sheltered from liability, have less of an incentive to take precautions against pollution releases. On the other hand, larger firms or plants may use and store large amounts of chemicals or hazardous wastes, with the potential for accidentally discharging larger quantities.[15]

To further capture the toxics riskiness of manufacturing processes in the state, we include among the regressors the amount of hazardous waste generated *per capita* in the state.

The key regressor STRICT is a dummy indicator for whether the state mini-superfund program prescribes strict liability in any given year.[16] Figure 1 shows that many, but not all, of the eastern states passed strict liability provisions relatively early, shortly after passage of CERCLA. In some states, such as New Jersey and Rhode Island, strict liability has been in place since the late 1970s. In the industrial Midwest, some states adopted liability relatively early (Ohio, Missouri), others later (Michigan), and, finally, some repealed strict liability in the mid 1990s.[17] Mountain states (presumably those where the mining industry is politically powerful) generally have not adopted strict liability, but there are some exceptions (e.g., Montana).

In most cases, liability standards are subject to interpretation by the state courts, based on the statutory language and common law arguments, advanced by the state (ELI, 1995). States upholding strict liability 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

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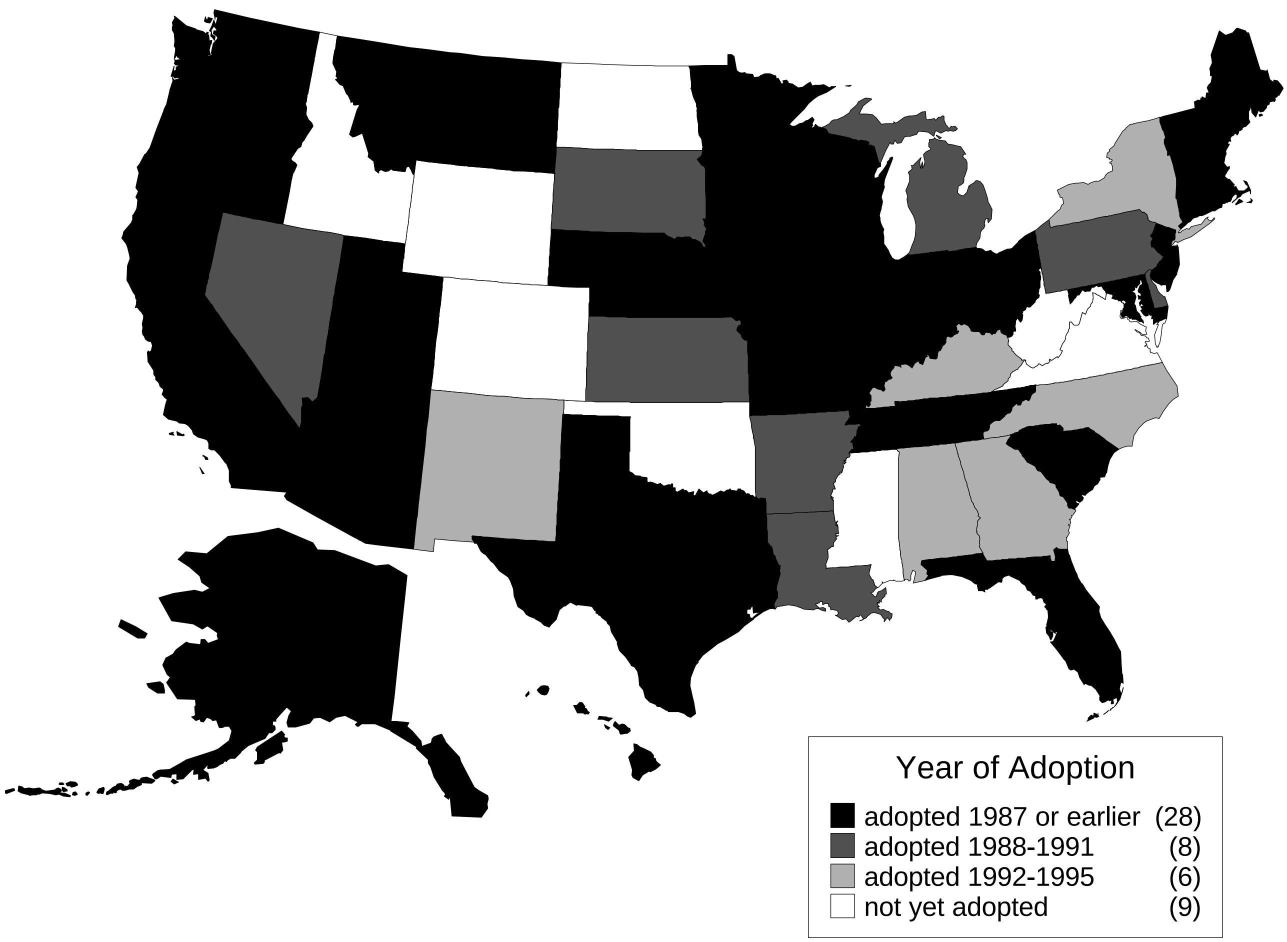
[14] Although establishments with fewer than 20 employees account for only about two percent of the total value of shipments from manufacturing firms, they are very numerous, making up about two-thirds of the total number of establishments. We repeated our analyses for other breakdowns into smaller and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

[15] Over 95 percent of all hazardous wastes are managed on-site by the generator. This is particularly true for large companies, which often opt for on-site management in hopes of better monitoring operations and avoiding involvement with faulty waste management facilities (Wentz, 1989). In addition, OSHA requires larger companies handling dangerous chemicals or hazardous wastes to prepare formal plans for handling emergencies, but waives this requirement for smaller firms (Wagner, 1999).

[16] Strict liability may 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 (EPA, 1989).

[17] In the early 1990s, Ohio briefly reverted to a policy based on negligence, re-instituting strict liability in its mini-superfund program by 1995. Illinois repealed strict liability in 1995.

Figure 1: State Adoption of Strict Liability



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. The negligence standards are established by the courts on a case-by-case basis. 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 relative to strict liability (ELI, 1995).

While many responsible parties avoid litigation by reaching consent agreements with the state agency, under either liability regime the incentives faced by firms should be influenced by the expected outcome of litigation. This may depend on the aggressiveness of the state agency in prosecuting polluters; on the perceived efficiency of the state court system; and on the perception of whether the courts tend to rule in favor of the defendant or the plaintiff in toxic tort lawsuits.

We measure the prosecutorial aggressiveness of the state as the number of lawyers working on state Superfund cases per million residents. The state court efficiency is captured by the ratio of all civil cases disposed of to all civil case filed, in any given year.[18] Lacking better statistics on state court rulings, we assume that state court preferences toward business activity and environmental quality are similar to the state's preferences. We proxy these preferences with the percentage of votes for the democratic candidate in the most recent presidential elections (PCTDEMPR), a widely used political variable.[19]

Additional explanatory variables include population density, and membership, per 1000 residents, in any of three major environmental organizations. These factors may encourage firms to avoid releases for fear that they will cause more severe damages, or will be reported to authorities by community residents.[20] However, chemical spills occurring in densely populated areas may cause greater harm, implying that the sign of the coefficient of population density variables is uncertain *a priori*.

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[18] Data from *Court Statistics Project*, National Center for Court Statistics, Williamsburg, VA.

[19] These three variables--prosecutorial discretion of the state, efficiency of the state court system, political preferences of state residents--also proxy for the *expected* stringency of the negligence standard established by the state courts in states maintaining negligence-based liability. We argue that it is such *ex ante* expectation that a firm will base its choice of care on.

[20] These variables also serve as controls for reporting effects across states. As in Alberini and Austin (1998), we think it reasonable that spills are hard to conceal in densely populated areas, and that environmentally aware populations are more likely to report spills. The latter effects may be partially or completely offset by firms' tendency to take care against pollution releases in areas populated by environmentally aware residents. Sigman reports some evidence in the ERNS data of differences in rates of reporting oil-dumping incidents across states. She attempts to control for reporting effects in her empirical estimations using covariates relating to reporting effort: total non-oil ERNS incidents, average personal income, and a dummy for Democratic governor. All are significantly and positively related to reported oil dumpings.

How a firm responds to the imposition of liability should depend in part on its ability to deflect payment of some or all of the damages to its insurance companies. Unfortunately, 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 omit insurance variables from the right-hand side of the spills equation, so that the effect of pollution insurance (if any) is absorbed into the coefficients of the included variables, to the extent that they proxy the demand and supply for pollution insurance. For instance, smaller firms may be unable to either self-insure or secure insurance coverage.[21] Finally, we include year dummies in our Poisson regressions.

B. Determinants of Liability Structure

The variables **w** influencing the liability policy and serving as instruments for it include predetermined economic and political characteristics of the state.

Specifically, we proxy uncontrolled toxics with the numbers of existing hazardous waste sites, past spills of CERCLA chemicals, and past injuries in spills of CERCLA chemicals. The numbers of small and large production units should capture both the toxics risk as well as the state's likely costs in running the remediation program, and thus affect the state's choice of liability structure.

We proxy the size of the exposed population using the state's population density. We also include state residents' educational attainment levels, because they are likely to affect the public's perception of the hazardous waste problem in the state, and the value of avoiding the illnesses associated with exposure to hazardous wastes (Tolley et al., 1994). Absent information about the administrative costs of the state hazardous waste programs, we assume that a program's net benefits are influenced by the state resources available to the "mini-Superfund" program, here measured by state expenditures *per capita* (drawn from annual US statistical abstracts) and the percent of state budgets dedicated to environmental programs (from Hall and Kerr, 1992).

Finally, the state legislature's net benefit calculus may be influenced by interest group pressure, attitudes of residents towards environmental quality, and attitudes of the state agencies towards the environment. These considerations suggest that political variables, such as the percent of popular votes for the Democratic candidate in the most recent presidential election, be considered among the determinants of net benefits.

5. RESULTS

A. Initial Results

We begin with a brief discussion of initial Poisson models of annual chemical-spill injury totals, reported in Table 2. The first column presents our basic specification, in which the indicator for strict liability is included in the right-hand side and treated as econometrically exogenous.

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[21] See Gastel (1998) for a discussion of pollution insurance issues.

In the second column, (B), we add three more dummy variables describing other features of the state mini-superfund programs. These indicate the presence of provisions for victim compensation in the state mini-superfund program; whether a state may impose punitive damages if it is forced itself to initiate the cleanup; and whether the statute allows private citizens to initiate actions against parties responsible for toxic releases lawsuits.

Table 2. Poisson regressions.
Dependent variable: Number of injuries. (t statistics in parentheses).
All specifications include year dummies.

	(A)Base specif.	(B) Other liability features	(C) State fixed effects
Constant	-7.5751 (-21.49)	-8.6094 (-23.14)	--
Log manuf Firms 20+ emp.	-0.7012 (-8.71)	-0.4728 (-5.20)	-7.0963 (-15.24)
Log manuf Firms 20 or less	1.5348 (18.46)	1.3433 (14.29)	5.2423 (11.64)
Log mining firms 20+ employees	0.4098 (7.92)	0.3669 (6.89)	0.7955 (5.14)
Log mining firms 20 or less	0.0412 (0.87)	0.1007 (2.03)	1.1592 (3.97)
HAZWASTE	0.0372 (3.02)	0.0453 (5.14)	
LPOPDENS	0.0847 (4.40)	0.0051 (0.17)	
ENVORG	-0.0075 (-0.85)	-0.0098 (-0.99)	0.7999 (8.36)
Strict liability dummy	0.7952 (18.50)	0.8775 (18.01)	0.3476 (4.47)
Citizen suit allowed dummy		-0.0909 (-2.22)	
Punitive damages		-0.4111 (-8.45)	
Victim compensation		0.2440 (4.70)	
LAWYERS	0.0362 (2.07)	0.0533 (3.03)	0.2407 (6.08)
CORTEFF	1.5153 (7.28)	1.7594 (8.27)	1.7336 (6.80)
PCTDEMPR	-1.4599 (-3.19)	-1.0550 (-2.30)	-10.825 (-14.09)
Sample size	362	362	362
Log likelihood	-14064.89	-14120.17	-14726.24

The first two variables capture additional aspects of firms' exposure to liability. We treat the citizen-suit 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. As this may permit closer oversight over firm behavior than the agency could achieve by itself, this variable is intended to help account for a firm's probability of being targeted by the state agency.

Treating strict liability as an exogenous regressor, we would conclude that injury totals increase with the number of small manufacturing units but decrease with the number of large units; that large *mining* operations are also associated with more severe spills; and that, as expected, injury totals rise with population density and quantity of hazardous waste generated.

The strict liability effect is significant, predicting that, all else the same, a state with strict liability would experience over twice as many injuries as a comparable state maintaining negligence-based liability. Including the other three policy variables has no effect on this coefficient, but, interestingly, the coefficients for citizen suit and punitive damages are negative and significant. This could suggest that strict liability is more effective if complemented by other measures. The victim-compensation effect is positive here, perhaps because states that have instituted victim compensation provisions are those that tended to experience severe consequences from chemical spills and accidents in the first place.

Finally, the coefficients of the year dummies (not reported in the table) show that in most years injuries are lower than their level in the first year in our data set, but they do not seem to decline in a monotonic fashion.

Why is strict liability positively associated with the severity of chemical spills? We offer four possible explanations for this striking finding.

First, strict liability may have triggered behavioral responses in firms that result in less care, and more severe accidents. A 1987 US General Accounting Office (GAO) study reports insurance industry assertions that "CERCLA's standards of liability…have reduced the availability of pollution insurance" and that "[strict] liability standards undermine incentives [of hazardous waste generators, transporters, and owners/operators of treatment storage and disposal facilities] to exercise due care to prevent pollution, because the standard of care is not related to the potential for liability." This view is not unanimous, since elsewhere in the GAO study, industry representatives are quoted as saying that "the standards of liability have in fact increased the standard of care taken by the industry."

A second explanation is that strict liability *per se* is not responsible for the greater spill severity and injuries, but is correlated with omitted factors that are. We fitted a fixed-effect model to see whether omitted state-specific factors drive the result. An insignificant coefficient of strict liability in the fixed-effects model would provide evidence in favor of this hypothesis.

The fixed-effects regression, reported in Table 2, column (C), rules out unobserved, state-specific factors as the sole explanation for heightened injury rates in states with strict liability. Although likelihood ratio tests show that the fixed effects improve the fit, the strict liability effect remains strongly significant. Its magnitude here is much smaller than in the pooled models of columns (A) and (B), but still implies that a strict-liability state can be expected to experience about 40 percent more chemical-spill injuries than a similar state with negligence-based liability.[22]

In what follows, we empirically explore our two remaining explanations for the positive association between spill severity and strict liability, namely that the strict liability dummy may be (econometrically) endogenous with spill severity, and, finally, that riskier industrial activities may have devolved, after the institution of strict liability, to smaller firms that were sheltered from full liability.

The latter story recalls Ringleb and Wiggins (1990). They find that after strict liability was instituted for long-term health effects on workers occupationally exposed to hazardous substances, many small firms--presumably sheltered from liability, due to their limited assets--were attracted into the industries with the highest potential liability. Strict liability for hazardous waste site cleanup may have produced a similar effect, encouraging companies to spin off, or delegate riskier operations, to smaller firms. In a number of well-publicized cases, this may have indeed happened, but it is not clear how widespread this phenomenon is.

B. Endogenous Liability

As earlier explained, we estimate a model that explicitly allows for endogeneity of spill severity and liability laws by using a two-stage procedure. Results for the first-stage probit equation for states' adoption of strict liability are reported in Table 3, where the dependent variable is the presence/absence of strict liability in state *i* in year *t* (with *t* ranging from 1988 to 1995)[23] and all independent variables are lagged one year.[24]

Table 3 shows the numbers of NPL sites and non-priority sites in the state are positively associated with the likelihood of imposing strict liability, although the respective coefficients are not statistically significant. Importantly, the past frequencies of spills of CERCLA chemicals and the past severity of such spills (the number of injuries) *are* positively and strongly associated with adoption of strict liability: the data suggest that strict liability is adopted in response to an underlying tendency to experience numerous and potentially severe releases of pollutants into the environment.[25]

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22 In practice, the fixed effects model allows for the endogeneity of the decision to adopt strict liability with spill severity, as its estimated coefficients are robust to unobserved factors correlated with the state's choice of liability regime. These factors might include variations in the prevalence of production processes posing particular spill risks; differences in standards of enforcement, which can influence firms' levels of care and accident rates; and in environmental insurance practices.

23 Our probit model treats all observations as serially independent within a given state. Alberini and Austin (1999) fit fixed-effects logit equations, and obtain qualitatively similar results.

24 Additional lags did not improve the explanatory power of the model.

25 Past spills and chemical-spill injuries remain strong predictors of the liability policy even when the number of NPL and non-NPL sites in the state are omitted from the equation. When past spills and injuries are omitted, the coefficients of the numbers of existing hazardous waste sites are positive and statistically significant. Although we believe that the number of existing hazardous waste sites, past spills and past spill-related injuries are all related to the adoption of strict liability policies, the effect of hazardous waste sites is muted by collinearity

The probit regressions results suggests that the more numerous a state's small manufacturing plants, and its large mining establishments, the less likely it is to adopt strict liability. States with a preponderance of small firms may anticipate the difficulty of getting such firms to pay for cleanup under strict liability, and may be motivated more by pollution problems arising from their manufacturing sector than from their mining activities, in adopting strict liability.[26]

Table 3. Probit Equation of Strict Liability Adoption

	Coefficient (t statistic)
Constant	1.1163 (0.44)
Log final NPL sites (lagged)	0.0946 (0.53)
Log state sites (lagged)	0.0486 (0.55)
Log spills of all CERCLA substances (lagged)	0.5050 (3.04)
Log total injuries in CERCLA spills (lagged)	0.2887 (3.35)
Log population density	-0.0802 (-0.59)
Log manuf firms 20+ employees (lagged)	0.5567 (1.24)
Log manuf firms 20 or less employees (lagged)	-0.9879 (-1.68)
Log mining firms 20+ employees (lagged)	-1.1121 (-1.68)
Log mining firms 20 or less employees (lagged)	0.2948 (1.16)
HIGHSCH (lagged)	0.0448 (1.32)
LESSTHS (lagged)	-0.0636 (-2.89)
Log state expenditure per capita (lagged)	0.2996 (0.89)
Pct state budget for environmental programs (lagged)	-0.0971 (-1.11)
Pct votes for Democratic candidate in presidential elections (lagged)	1.9228 (1.20)
Sample size	365
Log likelihood	-149.97

between these variables. Since the purpose of this procedure is to produce fitted values for the adoption of strict liability, we need not be too concerned with such collinearity.

26 An alternative interpretation for the negative and significant coefficient of larger mining establishments is that the extractive industry has effectively lobbied against imposition of strict liability.

Of the remaining variables, only education seems to have an effect: states with relatively low educational attainment levels appear less likely to impose strict liability. Although many variables are insignificant, probably because of collinearity between the independent variables, the model fits the data well, correctly predicting over 79 percent of the observations.

When the predicted probability that strict liability is in place in state *i* in year *t*, $\hat{\Phi}_{it} = \Phi(x_{it}\hat{\alpha})$, is entered in the Poisson equation for total injuries, replacing the strict liability dummy we employed in Table 2, we see that the estimate of γ, the coefficient of strict liability, becomes *negative* and significant. These results are shown in Table 4, column (A).[27] We conclude that, rather than causing an increase in spill rates, strict liability was introduced by states *already* experiencing numerous chemical spills or having a substantial contaminated site problem, and has proved effective at addressing such problems.[28] To check this interpretation, column (B) presents a Poisson regression over only the strict-liability observations: a regressor counting the "years since strict liability was adopted" has a significant, negative effect, showing that injuries slowly decline over time once strict liability is in place.[29]

Explicitly recognizing and handling the endogeneity of strict liability and spill severity with instrumental variable estimation changes the coefficients of many other variables. Comparing column (A) of Table 2 with that of Table 4 reveals that, for instance, the coefficient of the number of lawyers working for the state mini-Superfund program (normalized on a per million resident basis) turns negative: as expected, the stronger the prosecutorial discretion of the state agency, the higher the likelihood that firms will be prosecuted for pollution releases, and the more care firms will take to avoid spills or limit their damages when they do occur.

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[27] Replacing S_{it} with $\hat{\Phi}_{it}$ introduces additional heteroskedasticity of the dependent variable in the Poisson equation, and requires appropriately correcting the standard errors of the estimates. The correct asymptotic covariance matrix of the Poisson estimates is $\Sigma = R_2^{-1} + R_2^{-1}\left[R_3' R_1^{-1} R_3 - R_4' R_1^{-1} R_4\right] R_2^{-1}$, where R_1 is the information matrix of the log likelihood function of the probit equation, R_2 is the information matrix of the Poisson coefficients, $R_3 = \sum_i \sum_t (y_{it} - \lambda_{it})^2 \phi(\mathbf{w}_{it}\alpha)\gamma \mathbf{w}'_{it}\mathbf{x}_{it}$, $R_4 = \sum_i \sum_t (y_{it} - \lambda_{it}) M_{it} \mathbf{w}'_{it}\mathbf{x}_{it}$, and $M_{it} = S_{it}\phi(\mathbf{w}'_{it}\alpha)/\Phi(\mathbf{w}'_{it}\alpha) - (1 - S_{it})\phi(\mathbf{w}'_{it}\alpha)/[1 - \Phi(\mathbf{w}'_{it}\alpha)]$ (Murphy and Topel, 1985). Unfortunately, neither the LIMDEP packaged routine nor our own GAUSS code were able to produce finite estimates of Σ, presumably because of singularity in the "correction term" (the second term in the expression for Σ). We were, therefore, forced to use the "all-purpose" heteroskedasticity-robust covariance matrix calculated as $V^{-1}R_2V^{-1}$, where V is the outer product of the first derivatives of the Poisson log likelihood function (Fahrmeir and Tutz, 1994).

[28] In moving from Table 2, where policy variables are treated as exogenous, to Table 4, the additional policy variables **A** (citizen suit; punitive damages; victim compensation) are omitted because of the difficulty of estimating a model with four endogenous dummy variables.

[29] The coefficient of this variable implies that it takes about 5 years to reduce spills by about 10 percent. This is broadly consistent with the strict-liability effect estimated in column (A) of Table 4. All else unchanged, column (A) predicts that a state with strict liability would experience half as many injuries as a comparable state with negligence based liability--but the magnitude of γ is partially offset by the coefficients of the year dummies (not reported), which are positive for regression (A) in Table 4.

Similarly, the variable measuring the efficiency of the state court system now has a negative coefficient: given the aggressiveness of the state agency, promptly functioning state courts may imply a higher likelihood that a firm will have to pay for cleanup of its spills, encouraging the firms to avoid pollution releases. Neither effect, however, is statistically significant in Table 4 at conventional levels.

Table 4. Poisson Regressions.
Dep. var.: Number of injuries. (t stats in parentheses).
Specifications (A) and (C) include year dummies.

	(A) Endogenous liability[a]	(B) Strict liability states only	(C) Switching Regression Model[a]	
			Strict Liability Regime	Negligence-based Liability Regime
Constant	-5.4931 (-3.77)	-7.7873 (-18.65)	-9.6048 (-6.42)	0.8847 (0.64)
Log manuf Firms 20+ emp.	0.7182 (1.74)	-1.0240 (-10.38)	0.0367 (0.40)	1.7301 (2.42)
Log manuf Firms 20 or less	0.3302 (0.81)	2.0853 (21.02)	1.2376 (3.39)	-1.0970 (-1.32)
Log mining firms 20+ employees	-0.1820 (-0.51)	-0.3227 (-11.63)		
Log mining firms 20 or less	0.2821 (1.13)	0.6773 (4.97)		
HAZWASTE	0.0329 (3.463)	0.1147 (10.76)	0.0303 (0.75)	0.0660 (1.55)
LPOPDENS	0.0193 (0.72)	0.1988 (6.19)		
ENVORG	0.1035 (2.81)	0.0714 (8.19)		
Predictor for Strict Liability	-1.0050 (-5.68)			
LAWYERS	-0.0279 (-1.52)	0.0427 (1.76)	0.0384 (0.57)	0.2176 (2.30)
CORTEFF	-0.2159 (-0.88)	1.3283 (5.98)	0.6822 (2.92)	-1.3175 (-1.58)
PCTDEMPR	-4.316 (-2.21)	-7.7252 (-25.79)	-0.3645 (-0.87)	-3.6198 (-3.68)
Years since strict liability was adopted		-0.0205 (-4.18)		
Sample size	313	255	313	
Log likelihood	-8084.65	-13123.95	-8179.57 (second stage)	

[a]: Heteroskedasticity-robust t statistics.

Even more surprisingly, the earlier results about the contribution of large firms to spills appear to be reversed. Large manufacturing firms now appear to be associated with increased spills, while for large mining firms it is the reverse. We offer an explanation for this change in the next section.

C. Structural Changes

That the coefficients of small and large production plants switch sign when we implement the instrumental variable approach prompted us to check for structural changes across the regimes.

To investigate this possibility, we specify a switching regression Poisson model with endogenous switching. Switching regression models with endogenous switching are usually based on an assumption about the joint distribution (e.g., a bivariate normal density) for the outcome of interest and the latent variable underlying the regime. Due to the difficulty of dealing with joint distributions for count data and the net benefits of a liability regime, in this paper we follow instead the approach suggested by Greene (1995).

Specifically, we assume that (i) the marginal probability distribution of the liability regime is that of a Bernoulli variable with probability of strict liability equal to $\Phi(\mathbf{w}_{it}\alpha)$; and (ii) the probability distribution of total injuries, conditional on the liability regime, is a Poisson with expected value (and variance) equal to:

$$E(y_{it}) = \lambda_{it}^{N} = \exp(\mathbf{x}_{it}\beta_N + \theta \cdot M_{it}) \qquad \text{if } S_{it} = 0 \text{ (under negligence),} \tag{6}$$

and

$$E(y_{it}) = \lambda_{it}^{S} = \exp(\mathbf{x}_{it}\beta_S + \theta \cdot M_{it}) \qquad \text{if } S_{it} = 1 \text{ (under strict liability),} \tag{7}$$

where

$$M_{it} = S_{it} \cdot \frac{\phi(\mathbf{w}'_{it}\alpha)}{\Phi(\mathbf{w}'_{it}\alpha)} + (1 - S_{it}) \cdot \frac{-\phi(\mathbf{w}'_{it}\alpha)}{[1 - \Phi(\mathbf{w}'_{it}\alpha)]}.$$

In practice, estimation is carried out in two steps. In the first step, one fits a probit model of strict liability, using the estimated coefficients to form the term M_{it}. In the second step, a Poisson regression is run that includes M_{it} from the first step, and the matrices of regressors $\mathbf{X_0}$ and $\mathbf{X}_1$, where the rows of $\mathbf{X_0}$ are equal to $\{\mathbf{x}_{it} \cdot (1 - S_{it})\}$ and the rows of $\mathbf{X}_1$ are equal to $\{\mathbf{x}_{it} \cdot S_{it}\}$. The coefficients of $\mathbf{X_0}$ and $\mathbf{X}_1$ are β_N and β_S, respectively.[30]

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[30] As before, care must be taken to derive the covariance matrix that corrects for the use of estimates in the second-stage Poisson regression. Formulae for the corrected covariance matrix of the Poisson coefficients, derived following Murphy and Topel (1985), are presented in Greene (1995). Once again, however, we encountered difficulties in applying these formulae, and were forced to use the heteroskedasticity--consistent covariance matrix $V^{-1}R_2V^{-1}$.

Results from this estimation procedure are reported in Table 4, column (C).[31] A Wald test shows that inclusion of M_{it} to account for the endogeneity of the liability regime is appropriate: the Wald statistic is equal to 5.35, which falls in the rejection region of the chi square with one degree of freedom at the conventional significance levels.

Column (C) shows that in states with strict liability, the number of chemical-spill injuries is unrelated to the number of larger manufacturing establishments, while *increasing* with the number of *small* establishments. By contrast, in states imposing negligence-based liability, the numbers of *larger* manufacturing establishments is positively associated with chemical spill injuries. The magnitude of these coefficients suggests that in strict-liability states, a one-percent rise (fall) in the number of small plants results in a 1.24 percent rise (fall) in the number of injuries. This can be contrasted with the prediction that a one-percent change in the number of larger plants in a negligence-based state results in a 1.73 percent change, of the same sign, in the number of injuries. No such large-firm effect is seen in strict liability states.

This provides support for the hypothesis that strict liability may have induced spin-offs or delegation of risky production activities from larger to smaller firms in hopes of avoiding liability. Strict liability may indeed carry some perverse effects with regard to firm behavior, and these tendencies appear to be fairly widespread.[32] We conjecture that the reason why severe spills are associated with *larger* plants in states maintaining negligence-based liability may the scale to which chemicals are used in such plants. Among other things, the association between large plants and injuries in negligence-based liability states rules out worker safety requirements that vary with plant size as an explanation for our findings.

Of the remaining variables, LAWYERS has a positive coefficient in both regimes, but is significant only in the negligence-based liability regime. It is possible that this result is due to the endogeneity of the number of lawyers working in state mini-superfund cases and the injury outcomes.

We had no prior expectations about the sign of the coefficient of the state court efficiency variable. An inefficient state court system may favor either alleged polluters or the regulator, depending on the circumstances. The prospect of lengthy litigation and related expenses can act as a deterrent for certain firms, but be welcomed by others hoping to delay cleanup activities and disbursements. The results for the endogenous switching regression reported in Table 4 show that in states that maintain strict liability, more efficient courts are

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[31] We were forced to omit some regressors from the switching regression model to ensure convergence of the estimation routine. Greene (1995) warns that non-convergence is a relatively common occurrence with this kind of models.

[32] The changes in the signs and magnitudes of the coefficients of the various sizes and types of plants, seen when moving from the specification of Table 2, column (A) to that of Table 4, column (A), could then be an artifact of structural change between the two liability regimes. A likelihood ratio test based on the log likelihood for the Poisson model suggests that the structural change in the coefficients from one regime to the next is indeed significant.

associated with more severe spills. It is the opposite in states with negligence-based liability, where greater court efficiency seems to deter carelessness in handling toxic chemicals.

We speculate that the difference may be driven by the possibility that firms operating in negligence-based states are aware that the state agency will undertake litigation only when it has a strong case against the alleged polluter. A more efficient court system might, therefore, be associated with an increased likelihood of ruling against the firm, all else the same. That the court efficiency effect is positive in strict liability states suggests that these states are, on the whole, dominated by firms that associate lengthy litigation with increased costs, rather than with the opportunity to delay cleanup.

The result, emerging from earlier runs, that states where the general climate towards business is presumably less friendly--states with a greater tendency to support Democrats in presidential elections--tend to experience, all else the same, less severe spills, is confirmed here. Finally, there is no detectable time trend in the severity of spills: the coefficients of the year dummies (not reported) are for the most part insignificant.

By comparison, Alberini and Austin (1998) separately analyze spills of specific families of CERCLA chemicals (acids, ammonia, chlorine and halogenated solvents), and generally find that for the families with more numerous spills (acids, chlorine and ammonia), the effects of strict liability on spill frequency are similar to those seen here for spill severity.

6. CONCLUSIONS

We have estimated models of chemical-spill severity to see if it is influenced by state environmental policies based on liability. We find that the severity of unintended pollution releases *is*--all else the same--reduced by imposition of strict liability. It is clear that states have adopted strict liability *because* of their tendency to experience numerous spill events, and have managed to subsequently reduce spill events over time thanks to strict liability. Without explicitly modeling the reasons for state use of strict liability in environmental policies (using instrumental variable techniques), one would reach the conclusion that strict liability has *increased* the frequency or seriousness of spill events. In this sense, our results are similar to those reported by Levinson (1997) on the effects of state waste-end taxes and interstate shipments of hazardous waste. Both sets of results indicate the importance of checking for the endogeneity of environmental policies in analyses that exploit policy differences across states.

We also find evidence consistent with the hypothesis that firms have developed behavioral responses to avoid liability, when they are strictly liable for releases of hazardous chemicals into the environment. In states with strict liability, greater spill severity and frequency are associated with smaller production units (our proxy for firms with fewer assets), whereas this association is not present in states following negligence-based liability. It is possible that in a strict liability regime, firms deliberately select their corporate structures and asset levels to avoid liability, or that small firms have tended to specialize in riskier processes. In future research, we hope to perform individual-firm data analyses, incorporating information about pollution insurance, to seek additional evidence to support or refute this finding.

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