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LIABILITY, REGULATION AND ENDOGENOUS RISK: INCIDENCE AND SEVERITY OF ESCAPED PRESCRIBED FIRES IN THE UNITED STATES

by

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Liability, regulation and endogenous risk: Incidence and severity of escaped prescribed fires in the United States

ABSTRACT

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Prescribed fire is a useful but risky method for reducing general wildfire risk and improving wildlife habitat, biodiversity, timber growth, and agricultural forage. In the past the fifteen years, laws is some states have been adopted to support the use of prescribed fire. This article examines the effect of liability law and common regulations on the incidence and severity of escaped prescribed fires in the United States from 1970 to 2002. Regression results show that stringent statutory liability law and regulation tends to reduce the number and severity of escaped prescribed fires on private land, but not on federal land where state liability law does not directly apply.

Keywords: endogenous risk, prescribed fire economics, liability law

JEL Codes: K32 - Environmental, Health, and Safety Law; Q2 - Renewable Resources and Conservation, Environmental Management.

1 Introduction

Aboriginal Americans used fire extensively to cultivate native grasses, to modify forest vegetation, and to facilitate hunting. This cultural use in conjunction with the natural occurrence of fire was an important determinant of the ecological landscapes that existed during European colonization of North America (Kimmerer and Lake 2001, Pyne 1982 1991). In the early twentieth century, the U.S. federal land management agencies other related institutions shifted emphasis away from active prescribed fire use to focus virtually exclusively on fire suppression, a shift in management symbolized by the creation of Smokey the Bear in the mid 1940s(Carle 2002, Pyne 1982).[1] As a result of these suppression efforts, the structure of forests and prairies has changed. In recent decades it has become increasingly evident to fire researchers and land managers that these changes have produced vegetation structures more conducive to large, hard to control catastrophic fires (Carle 2002, Babbitt 1995, Cooper 1960).[2] Furthermore, empirical research increasingly suggests that fire holds unique capabilities for improving biodiversity and agricultural productivity. (Carle 2002, Zimmerman 1997, Briggs and Knapp 1995, Babbitt 1995, Cooper 1960).

So, after a century of emphasis on wildfire suppression, there is a resurgence of interest in using prescribed fire as a management tool in many parts of the United States. The Federal government now formally recognizes prescribed fire as an integral element of wildfire management on federal lands (U.S. Department of the Interior, U.S. Department of Agriculture 1995). Cleaves et al. (2000) report that the number of national forests using prescribed fire increased by 76% between 1985 and 1994. About 900,000 acres of Federal land was treated with prescribed fire in 1995, and the annual acreage treated had increased to 2.2 million by 1999 (National Interagency Fire Center 2001). The Healthy Forests Restoration Act of 2003 includes substantial emphasis on fuels management to address forest health and wildfire concerns. In principle, the Act calls for increases in the use of prescribed fire and mechanical thinning to reduce fuel loads, and it dictates that these efforts should concentrate primarily on the wildland urban interface.

Prescribed fire is nonetheless a risky management tool, and this resurgence of interest is accompanied by renewed legislative attention and regulation in many states. For example, in the last 15 years many southeastern states have enacted legislation that explicitly recognizes that careful application of prescribed fire provides public benefits. These statutes tend to clarify liability standards relative to common law and their statutory precursors, in some cases they reduce the burden liability for burners substantially, while simultaneously institute more stringent regulations over prescribed fire use. In Florida and Georgia for example, certified burner managers now who satisfy more stringent and detailed preparation documentation requirements face only a gross negligence standard rather than simple negligence or strict liability in the event of an escape.

Because of the potentially high costs of escaped prescribed fire, legal liability is often cited as a major concern by people using prescribed fire as a land management tool, and it is among the most often cited reasons for *not* using prescribed fire (Brenner and Wade 2003, Hesseln 2000, Haines and Cleaves 1999). Law and regulation affects the incentives of individuals for taking risks and for exerting precaution in the process (Roe 2004, Kolstad et al. 1990, Brown 1973, among many others). Thus, as is the case with many human activities (Shogren and Crocker 1999), the likelihood of escape and the scale of subsequent property damage is endogenous; a consequence of the behavior of prescribed burners and their neighbors, which in turn is affected by the institutional environment in which they operate.

This article examines the effect of liability law and common regulations on the incidence and severity of escaped prescribed fire. The analysis is based on data from 1970 to 2002 from the National Interagency Fire Management Information Database (NIFMID), in conjunction with a categorization of state statutory law. The regressions analyses control for various factors that affect baseline risk and incentives for precaution, such as land values, population demographics, the overall incidence of wildfires, and other factors. Results show that the incidence of escaped prescribed fires originating from private landowners or their agents tends to be lower in states with more stringent statutory liability law and regulatory restrictions. Public employees using prescribed fire on federal land face federal law that does not vary across states, and the results suggest that this group of prescribed burners are not responsive to variation in state law in the same way that private land managers are.

A theoretical foundation and testable hypotheses are developed in the next section to support the empirical analysis. The data are described in section 3, estimation methods are outlined in section 4, results and interpretation are presented in section 5. Section 6 concludes.

2 Theory

Consider a set of heterogenous landowners, each of which stand to gain benefits from prescribed fire, but also face costs and risks associated with its use. Assume the *ex ante* net expected value of a prescribed fire for any given landowner is

$$v = b - \rho d(x,z)\varepsilon - wx, \tag{1}$$

where $b \sim (\bar{b}, \varsigma^2) \in [0,\infty]$ represent benefits from a prescribed fire that are randomly distributed across land parcels but known *ex ante*, $\rho \geq 0$ is an index that represents the relative stringency of liability law across states.[3] The function $d(x,z)$ represents expected damage from an escaped prescribed fire, and depends on endogenous precaution x and environmental characteristics z. The random disturbance ε is distributed $(1,\sigma^2) \in [0,\infty]$ so that $d(x,z)$ is *ex ante* expected damage and also (aymptotically) *ex post* mean damage. The marginal cost of precaution is w.

The stringency index ρ is a stylized representation of the effects of liability rules on the risks faced by prescribed burners. Three fundamental forms of liability are examined in the empirical analysis: strict liability, simple negligence, and gross negligence. Consider the relative effects of each of these on the expected costs on the burner in a very simple setting with no evidentiary or judicial uncertainty. Given strict liability, the burner always pays damages regardless of precautionary effort, and damage given an escape may be high because potential victims (who will be compensated in the event of property damage) have little or no incentive for self protection. Under a simple negligence rule with an efficiently set standard, the burner will expend just enough effort to satisfy the standard, and therefore will not pay damages (Brown 1973). Under gross negligence, the standard is set lower than under simple negligence. The burner will again choose to satisfy the standard, but will need to exert less effort to do so than under simple negligence. Thus, for these three general forms of liability, the relative ranking from least to most stringent would be a) gross negligence, b) simple negligence, c) strict liability; the stylized index ρ as defined would be increasing in that order. The treatment of ρ in equation 1 is does not perfectly mirror the sources of stringency, but it is a sufficient and convenient heuristic for deriving comparative statics. [4]

In addition to civil liability, some states have codified criminal liability law. These statutes generally state that if an individual is found to have performed a prescribed fire in a negligent fashion, the individual faces not only civil liability, but criminal liability as well. Such a statutory rule presumably increases the expected costs of negligence beyond that of civil liability alone. Thus, for a given civil liability rule, a criminal negligence law would be associated with a higher ρ.

Necessary and sufficient conditions for maximizing the expected value of equation 1 are $d_x < 0$ and $d_{xx} < 0$ (subscripts denote first and second derivatives). Given that prescribed burners maximize the expected value v of a burn by choosing $x^* = x(\rho, z, w)$ that satisfies $-\rho d_x - w = 0$, the effect of ρ on the level of precaution is then

$$x_\rho = -\frac{d_x}{\rho d_{xx}} > 0,$$

where, again, subscripts denote first and second derivatives. This comparative statics result will support a number of hypotheses to be developed in the next section and then tested empirically.

First, based on the Envelope Theorem, the effect of a change in ρ on the expected net benefits of prescribed fire is

$$\frac{\partial v(\rho, z, w)}{\partial \rho} = -d(\rho, z, w) < 0,$$

Given that b varies across landholdings but is known *ex ante*, some individuals with small but positive net benefits under one legal regime will chose not to burn under a different regime with higher ρ. Suppose the fraction of land parcels for which $v > 0$ is $1 - F(v(\bar{b}, \rho, z, w))$, where $F(\cdot)$ has the characteristics of a cumulative density function and accounts for both sources of random variation (b and ε). The total number of prescribed fires is

$$n(N, \bar{b}, \rho, z, w) = N[1 - F(v(\cdot))],$$

and total expected aggregate damage is

$$D(N, \bar{b}, \rho, z) = n(N, \rho, \bar{b}, z)d(\rho, z, w).$$ [5]

It is useful now to divide expected damage into to parts. Let $d = \delta(x, z, w)\pi(x, z, w)$, where $\delta(\cdot)$ is expected property damage (or average damage) per fire given an escape and $\pi(\cdot)$ is the probability of escape (or the proportion of prescribed fires that escape).[6] The division of d into potential damage and the probability of escape means that the expected number of escaped prescribed fires can be defined as $n(\cdot)\pi(\cdot)$. Based on the above model, the effect of increased stringency on aggregate number of fires and escaped fires are:

$$\frac{\partial n\pi}{\partial \rho} = n\pi_x x_\rho - fN\delta\pi^2 < 0, \tag{2a}$$

$$\frac{\partial \delta}{\partial \rho} = \delta_x x_\rho < 0, \tag{2b}$$

$$\frac{\partial D}{\partial \rho} = -[nx_\rho(w/\rho) + fN(\pi\delta)^2] < 0, \tag{2c}$$

where f is the probability density function associated with F. These comparatives statics results imply the following hypotheses that are testable with the available data:

Hypothesis 1. *Fewer prescribed fires will escape under more stringent liability rules* (2a).

Hypothesis 2. *Damage per escape will be lower under more stringent liability rules* (2b).

Hypothesis 3. *Aggregate damage from escaped prescribed fires will be lower under more stringent liability rules* (2c).

In addition to tests about the effects of civil and criminal liability rules, the effects of direct regulation will be examined. Regulatory *permit systems* that restrict the number and timing of prescribed fires in order to limit risks will tend to lead to fewer escaped prescribed fires and fewer acres of wildfires originating as prescribed fires. *Burn ban* statutes allow states and counties within states to restrict the use of prescribed fires during certain times of year and/or certain conditions.

Unlike private individuals, federal employees carrying out their duties on federal land do not directly face state liability and criminal laws. Rather, they face liability under the federal Tort Claims Act.[7] Therefore, strictly speaking, variations in state liability law should not lead to significant variations in the incidence and severity of escaped prescribed fires started by federal employees and originating on federal land. This unique setting provides a basis for another testable hypothesis:

Hypothesis 4. *State liability law will have little or no systematic effect on the number and severity of escaped prescribed fires started by public employees on federal land.*

One exception to the difference between federal employees and state law is that federal employees planning prescribed fires generally apply for prescribed fire permits if a state requires them, and they generally abide by state burn bans when they are imposed. Therefore, although liability law ought not in principle have an effect on the behavior of federal employees on federal land, direct state regulatory restrictions may have more of an effect.[8]

A number of southeastern states have implemented "certified burner laws, " or "Prescribed Burn Manager" laws (PBMLs). These laws outline a relatively detailed set of rules and guidelines. If a prescribed burner is certified through a state sanctioned prescribed burning certification process and a specific prescribed fire plan and implementation satisfied the rules laid out in the statutes, the burner is provided more protection than otherwise (Brenner and Wade 1992). In a couple of cases such as Florida and Georgia, a certified burner who satisfies the statutory requirements must be found grossly negligent in order to be held liable for damage from an escaped prescribed fire. The effect of this combination of direct regulation and a gross negligence rule is an interesting one. On the one hand, stricter requirements presumably mean that fewer prescribed fires will escape and the number of severe escapes will decrease if the requirements are effective. On the other hand, holding regulations constant, a gross negligence rule will tend to reduce the level of precaution required to satisfy the liability rule, which in turn reduces the costs of prescribed fire and should increase the incidence of escape. Holding PBMLs constant, gross negligence rules should induce more, and more severe, escaped prescribed fires than other states. To summarize:

Hypothesis 5. *States with strict PBMLs will tend to have lower incidence and severity of prescribed fires.*

Hypothesis 6. *States with gross negligence rules will tend to have more, and more severe, escaped prescribed fires.*

Other nonlegal factors also affect the use of prescribed fire and precaution during use. These are factors that affect the size of the benefits, b, elements in z that affect the size of expected damage from escape d, and the costs of prescribed fire precaution w. For our purposes, these amount to factors that should be accounted for in regressions to reduce bias in estimation of the legal parameters of interest. For example, prescribed fire will tend to be used less, and precaution will be higher when potential damage from escape is large. The proxy variables used in the regressions to represent these factors will be discussed in sections 3 and 5, but an example of an element of z that is important to control for is the overall propensity for wildfires and wildfire severity in a region. This factor is accounted for by including explanatory variables representing the characteristics of wildfire that were not started as prescribed fires.

3 Data

The data used in this analysis come from a number of sources. The data on fire characteristics is from the National Interagency Fire Center (NIFC). Variables representing state-level law and regulation were constructed from state statutes and verified through cross-referencing with other published sources as well as telephone conversations with agency employees. Descriptions and summary statistics of variables used in the estimation are presented in table 2 on page 33. The following subsections describe the data in more detail.

State law. Table 1 provide summaries of state statutory law. Most states with statutory law relating to prescribed fire explicitly specify a negligence rule. In the absence of statutory law, state-level common law forms the basis for court decisions about prescribed fire liability, and common law tends to be predicated on negligence rules (American Law Reports Editorial Staff 1994). Four states, however, impose strict liability on prescribed burners — Connecticut, North Dakota, New Hampshire, and Oklahoma. If a fire escapes, the burner is liable for damage regardless of his or her effort to contain the fire. There are a great many subtle differences in statutory liability law for prescribed fire across states, but we focus only on the two fundamental forms, strict liability and negligence rules.

[Table 1 about here.]

Permits and fire bans can be interpreted as a regulatory attempt at reducing the number of high risk prescribed fires. From an economic perspective, the potential of facing criminal penalties for negligence will tend to increase the perceived costs of negligence, and so will have the effect of reducing accidental escape by increasing incentives for investing in precautionary effort. It turns out that there is a near one-to-one match between the states with statutes that support permits and states with statutes that support burn bans — the two have historically been implemented at the same time. Therefore, it is not possible to separate the effects of these two regulatory factors in this analysis. Any discussion below of the effects of burn bans or of permit systems should be interpreted as the effects of either one, the other, or both.

The potential effect of Prescribed Burn Manager (PBM) laws are more complex. These laws tend to reduce the stringency of liability that prescribed burn managers face, but only if they satisfy a relatively strict set of guidelines. In two cases, Florida and Georgia, PBMs are now liable only if found grossly negligent as long as an explicit set of regulatory conditions are met.

Fire data. The National Interagency Fire Management Integrated Database (NIFMID) includes approximately 380,000 observations on individual fires from 1970 through 2002 for all states except Connecticut, Hawaii, Iowa, Massachusetts, Maryland, New Jersey, or Rhode Island (NIFMID 2004a). The states missing from NIFMID are not states with substantial wildfire activity, but this set includes one of the four states that have strict liability laws — one of the legal parameters of interest for this analysis.[9] The data descriptions that follow rely on the NIFMID technical guide NIFMID (2004b). In addition to an incomplete set of states, there is almost complete lack of data on escaped debris fires (and other categories of human cause fires) for the years 1986 through 1995. Data on resource damage estimates are also missing for those years. Therefore, all analysis is based on the years 1970 – 1985 and

1996 – 2002. Donoghue (1982) provides a discussion of the history and reliability of wildfire reporting.

[Table 2 about here.]

Sample selection. The estimation approach is to select two separate samples of escaped prescribed fire observations from the NIFMID database: one including fires originating from private land and one including fires originating from federal land. The sample is then aggregated to the state/year level because laws are state level explanatory variables. Regressions of interest are then estimated based on the aggregated data.[10]

A debris fire is assumed to have been started by a private landowner or his or her agent if it was started on "State and private lands inside National Forest Boundary" and "outside National Forest boundary", and if the igniter was "local permanent" and an "owner", "permittee", or "contractor".[11] A debris fire is assumed to have been started by a public employee on federal land if it was started on "National Forest" or "other Federal Land inside NF boundary" and by a "public employee" or "local permanent".[12] Although not perfect categorizations, these definitions fit as closely as possible given the data definitions.

The NIFMID data relate to wildfires. For a wildfire started as a prescribed fire, the acreage and damage included in the dataset pertain to the wildfire acreage and damage that occurred outside the prescription. The acreage originally in the prescription is not included. That is, all observations used in this analysis pertain to wildfires. The central focus of the analysis are characteristics of wildfires that happened to be started as prescribed fires.

There are a number of weaknesses associated with the NIFMID data. It does not provide information on the number of prescribed fires started or the fraction that escape. Individual wildfire response team managers fill out a standardized form (USDA Froest service form FSH 5109.14), and the definitions of the data requested are in some cases not defined very clearly. Furthermore, the requested data are in some cases omitted. To the extent that data omissions or misinterpretations affect independent variables, or are otherwise systematic, bias might be introduced into the regression estimates.

Dependent variables. For a given state, year, the dependent variables used in the regression analysis are: 1) the number of escaped prescribed fires, 2) the estimated damage plus suppression costs incurred in total and per fire, 3) the total and average size, in acres, of escaped prescribed fires. Note that these dependent variables correspond exactly to the testable hypotheses 1 through 3, and can be used to test the hypotheses 4 and 6 as well.

The number of escaped prescribed fires occurring in a given state and year represents the number of escapes, and the latter two dependent variables, damage plus suppression costs and acreage, are proxies for the extent of damage given that a fire escapes. The *sum* of the estimated resource damage plus suppression costs is used to represent the costs of escapes, because the two are in a sense endogenously determined, depending on the suppression expenditures of the fire-fighting agency, such that if suppression expenditures increases for a given fire, damage is lower than it would be. Therefore, using one or the other is an incomplete measure.[13]

Explanatory variables Other factors affect prescribed burners' incentives for precaution and the risks of escape. The variables described below are used to control for non-legal factors affecting expected costs and risks associated with prescribed fire use.

The general propensity for wildfires is dependent on the characteristics of the vegetation and environment in which the prescribed fires occur, and will have an important effect on both the usefulness of prescribed fire and the risks associated with using it. Therefore, the incidence and severity of wildfires from other causes can be used to control for the general propensity for wildfires in a state and year. The empirical distributions of the number, total resource damage and average suppression cost plus damage are shown in figures 1.

[Figure 1 about here.]

The value of rural land is dependent largely on the value of the productivity of land. The crops, timber, forage, and other vegetative output represent, in this case, potential damage from an escaped prescribed fire. Therefore, land value, *Land value* ($1000s per acre, deflated by the national CPI) is being used as one proxy for potential damage from escaped prescribed fire (U.S. Department of Agriculture 2003). *Average farm size* (in acres) is available from the Agricultural Statistics Database (U.S. Census of Agriculture 2004).[14]

Land cover type affects the propensity for prescribed fire use as well as wildfire risk and severity. *State grass acreage* is is the sum of the acreage of "Pastureland" and "Rangeland", and *State forest acreage* is the variable "Forest Land". *Median patch size* is estimated median diameter in feet of wildlife habitat patches (it is right-censored at 1000 feet), and proxies for vegetation fragmentation (National Resources Inventory 1997a). These data are from NRI Table 2 - Land cover/use of nonfederal rural land, by state and year (data per 1,000 acres) (National Resources Inventory 1997b). The data span 1982 to 1997, with observations every five years. Data were interpolated linearly within between data points for annual estimates, and were set to the 1982 and 1997 values for years before and after, respectively.

Human population density, *Population density* is also being used as a proxy for potential damage, because higher human populations are associated with more residential and business structures and more health risks from escaped fire. Increases in either of these variables are hypothesized to reduce the number and total acreage of escaped prescribed fires. Population estimates for 1970 to 2002 were compiled based on US Census Bureau intercensal data tables (U.S. Census Bureau 2001 2004). Population density was estimated by dividing population for each year by the total land area of the state as reported in National Resources Inventory (1997b).

4 Estimation

As outlined before, regression functions are estimated for three types of dependent variables: 1) the *number* of escaped prescribed fires, 2) the *total* size and damage of escaped fires, and

3) the *average* size and damage of escaped prescribed fires. The distributional characteristics of these dependent variables calls for a different estimation method in each case.

The number of escaped prescribed fires is count data, and data such as these are often represented by and estimated with Poisson distributions and Poisson regressions. Likelihood ratio tests show however that overdispersion is apparent in each case, so Negative Binomial regressions are applied instead (Greene 2003, pp. 740-744).[15] Estimated elasticities for the Negative Binomial regression based on an exponential mean function are

$$\epsilon_i^{nb} = (y_i/\mathbf{x}_i)\boldsymbol{\beta}\exp[\mathbf{x}_i'\boldsymbol{\beta}].$$

Total damage and acreage. When no escaped prescribed fires are recorded for a given state and year in the sample, the total size and damage of escaped prescribed fires is zero, and many observations on fire acreage and damage have values of zero. Therefore, a Tobit regression is applied to account for censoring of the dependent variable. All non-binary variables are transformed to natural logs before prior to estimation because the estimated disturbances in preliminary regressions appeared approximately log-normal for the non-censored observations. Therefore, the estimated elasticities for an observation i of a non-binary variable in the Tobit regressions are

$$\frac{\partial E[\ln(y_i)|\mathbf{x}_i]}{\partial \ln(\mathbf{x}_i)} = \boldsymbol{\beta}\Phi\!\left(\frac{\boldsymbol{\beta}'\mathbf{x}_i}{\sigma}\right).$$

Using the transformation for dummy variables in logarithmic equations developed by Kennedy (1981), the percent difference corresponding to one dummy variable $\mathbf{d}_j \in \mathbf{D}$ under normally distributed disturbances are

$$\frac{\Delta E[\ln(y_i)|\mathbf{x}_i, \mathbf{D}_i]}{\Delta d_j} = (\exp[\beta_j - 0.5v_j] - 1)\,\Phi\!\left(\frac{\boldsymbol{\beta}'\mathbf{x}_i}{\sigma}\right) \quad (3)$$

where by definition Δd_j is 1 or -1, and v_j is the variance of β_j. The estimate of this effect is calculated by replacing the unknown parameters with their maximum likelihood estimates.[16]

Log transformations cannot be performed when a variable takes the value of zero (the natural log of zero is $-\infty$). This case is common, particularly for the dependent variable. Therefore, values of zero were changed to 0.0001 prior to taking the logarithm. The lower bound for the dependent variable in the Tobit model as estimated is therefore $\ln(0.0001) \approx -9.21$.

Average damage and acreage per fire. For the observations in which the total acreage and damage are zero, the average acreage and damage is undefined and therefore missing. The same factors that affect the average escaped prescribed fire size (given tat least one escaped prescribed fire) also is likely to affect whether the observation is missing. Ignoring this sample selection process can result in biased parameter estimates. Therefore, a Heckman model for sample selection is estimated when average acreage or damage is the dependent variable. If a test for sample selectivity does not indicate sample selection, ordinary least squares estimates are reported instead.

The estimated elasticity vector from a Heckman sample selection model with non-binary variables in natural log form is

$$\frac{\partial E[\ln(y_i)|\text{in sample}]}{\partial \ln(\mathbf{x}_i)} = \boldsymbol{\beta} - \boldsymbol{\gamma}\beta_\lambda \delta_i(\mathbf{w}_i'\boldsymbol{\gamma})$$

where $\mathbf{x}$ and $\boldsymbol{\beta}$ is the matrix of explanatory variables and vector of parameters in the second stage regression of interest, and $\mathbf{w}$ and $\boldsymbol{\gamma}$ are the variables and parameters in the selection equation, and $\delta_i = \lambda_i(\lambda_i - \mathbf{w}_i'\boldsymbol{\gamma})$ where $\lambda_i = \phi(\mathbf{w}_i'\boldsymbol{\gamma})/\Phi(\mathbf{w}_i'\boldsymbol{\gamma})$ is the inverse Mills ratio evaluated at observation i. Although not explicit in the notation above, non-binary variables in $\mathbf{w}$ are in natural logs. For the percent change due to dummy variables, the Kennedy (1981) transformation is applied as in equation 3.

In these regressions on average wildfire and damage, the observations represents an average based over the number of escaped debris fires. Thus, the variance of the sample averages will diminish with the number of fires in a given state and year. This fact is accounted for in regressions by performing weighted maximum likelihood estimation, where the weights are defined as $1/\sqrt{n_i}$, where n_i is the number of observations used to generate the averages for regression observation i in the aggregated dataset.

All estimation and graph generation was performed using the statistical software [Intercooled] Stata version 8.2.

5 Results

Table 3 presents regression results for two sets of regressions. The first set correspond to debris fires that were started on private land, and the second set correspond to debris fires started on Federal land by public employees. The dependent variables for each set are:

- The number of escaped prescribed fires (*# fires*),
- Total resource damage and suppression costs of escaped fires (*tot.d+s*),
- Total acreage of escaped debris fires (*tot.ac.*),
- Average resource damage and suppression costs (*avg.d+s*)
- Average acreage of escaped fires (*avg.ac*).

The estimates shown correspond to elasticities for continuous variables and the percent differences for binary explanatory variables.

The first five rows of variables in the regressions in table 3 are the dummy variables representing state prescribed fire law and regulation. Each takes the value one if the law described by the name and label in table 2 is in effect for that state and year. The rest of the variables other than the constant are proxies for state characteristics that affect the risks associated with prescribed fire. The final six rows in the regressions provide selected regression summary statistics. The base case is a state with a negligence liability rule, no criminal penalties for negligent burning, no permit requirements, and no prescribed burner laws (that is, all legal dummy variables equal zero).

[Table 3 about here.]

5.1 Liability and regulation

All else constant, the signs on the first four of these legal/regulatory variables are hypothesized to be negative for each private-land regression because each is in theory designed to limit the number and/or severity of escaped prescribed fires. In contrast, *PBM gross negligence* reduces liability for certified prescribed burners if certain requirements are met by the burner. Holding other laws constant, *PBM gross negligence* is hypothesized to reduce the expected costs of prescribed fire for burners, reduce the level of necessary precaution to satisfy gross negligence, and so should have a positive sign.

Private land. States and years with strict liability laws (for which the variable *Strict liability* equals one), tend to have fewer escaped prescribed fires. Based on the *# fires* regression estimated percent difference of -12 percent (corresponding to the parameter estimate of -0.12), strict liability states tend to have 1.98 fewer escaped prescribed fires per year than do comparable states with negligence rules based on sample means. Based on sample medians, strict liability states tend to have 5.97 fewer escaped prescribed fires per year.

Based on the *ln(tot.d+s)* and *ln(tot.ac)* regressions, strict liability appears to have a substantial effect on the total damage and acreage of escapes per year — an estimated reduction of over 90 percent in each case (corresponding to parameter estimates of -0.92 and -0.97, respectively). The marginal effect of strict liability on the unconditional expected value of *d+s* evaluated at the sample means is \$-33,035 per year; at sample medians, the effect is about \$-93 per year. The *ln(tot.ac.)* regression indicates that states with strict liability laws have have an unconditional expected value of 140.0 fewer burned acres per year from escaped prescribed fire based on sample means, and 6.0 fewer acres based on sample medians. Based on the *ln(avg. d+s.)* and *ln(avg. ac.)* regressions, individual escapes leads to an estimated average of \$5,577 reduction in *d+s* and escapes an average of 7.9 acres smaller per fire; or

$449 and 1.9 acre reduction per fire respectively based on sample medians.

The estimated effects of *Permits / burn bans* are negative in all private land regressions, although not significantly so in the *ln(tot. d+s)* regression. Evaluated at the sample means, states with burn bans and/or permits have on average 1.2 fewer escaped prescribed fires, $27,513 less *d+s*, and 26.7 fewer acres burned from escaped fires. Average wildfire area from escaped prescribed fires is 2.4 acres smaller.

Criminal penalties represents states with laws that impose criminal penalties for negligent prescribed burning. The elasticity estimates for the private land regressions are negative and significant for two of five regressions, and positive but insignificantly so for two regressions. Private individuals seem to react less to criminal penalties in comparison to civil liability and permit/burn bans.

The parameter estimates for prescribed burn manager laws *PBM law* and *PBM gross negligence* are not significantly different from zero in most of the private land regressions. Furthermore, in two cases, the *PBM gross negligence* parameters are significant but negative, which is counter to hypothesis 6. It is important to note however, that these laws pertain to a smaller set of southeastern states in relatively recent years, and apply only to a smaller subset of potential burners. It is therefore perhaps not too surprising that they show weak effects. This set of laws will be revisited below with regressions based on a more focused subset of data.

Public employees on federal land. State law often does not, strictly speaking, apply to federal employees. Therefore, no discernable relationship is expected between state liability law and the incidence and extent of escaped prescribed fires from federal land. The results presented in table 3 for public employees on federal land are strikingly different from those for private land. In general, either the legal parameter estimates are not significantly different from zero and/or they have an unexpected sign. The only exception is the set of parameters associated with *criminal penalties*, which are all negative and in three cases significantly so.

The results for this explanatory variable notwithstanding, the effects of state liability law and regulation appear to have a very different, and weaker effect on federal employees than on private individuals, as expected.

[Table 4 about here.]

Because a vast majority of federal land resides in western states, separate regressions were run for western states only, US forest service regions 1 through 6. The top rows of table 4 provides a synopsis of the results pertaining to legal variables. Because no Prescribed burn manager laws nor gross negligence laws apply to western states, these two variables were omitted from the regressions.[17]

The results are similar to the regressions in table 3, except that *permits/burn bans* and *criminal penalties* have stronger and more consistently negative estimated effects on the number and size of escapes. Based on this more focused sample, public employees on federal land appear to be responding to state criminal law and state permit and burn ban requirements, but, as noted before, not state civil liability law. These results are generally consistent with hypothesis 4.

Private contractors on private land To date, all of the new generation of prescribed fire statutes pertaining to prescribed burn managers are located in western states (see table 1. Furthermore, the regressions presented in table 3 for *PBM law* and *PBM gross negligence* show weak or counterintuitive results. Therefore, a more focused sample is used to reexamine these effects. A sample was constructed that represents only escaped prescribed fires that were started on private land by contractors in southern states, defined as those states in US Forest Service region 8. A summary of the legal parameters for these regressions are presented in the second half of table 4.

Based on hypotheses 5 and 6, we expect *PBM law* to have a negative sign, because these laws tend to impose substantial requirements for preparation and precaution. *PBM gross negligence* should have a positive sign to the extent that weakening liability law reduces expected costs or performing a prescribed fire and reduces the level of precaution necessary to satisfy the negligence standard.

For both variables, the results provide stronger support for hypotheses 5 and 6 than the larger samples. The coefficients on *PBM law* are negative in all cases and significant at the 5 percent level or above in four of the five cases. The coefficients on *PBM gross negligence* are positive in all but one case, but significant (and positive) in only one. Even though contractors need not necessarily be certified and thus are not necessarily covered by these laws, the effects of these laws seem to be reflected in the more narrowly focused sample.[18]

5.2 Other factors

The five rows in table 3 directly below the elasticity estimates for the legal variables are variables that attempt to control for the general propensity for wildfire occurrence and severity. They are different for each regression. The number of other (non-prescribed) fires is included in the *#d.fires* regression, the total acreage of non-prescribed wildfires in the *ln(tot.d+s)* regression, etc. In each regression, the corresponding variable is positive and significant. Notably, each of these elasticity parameter estimates are less than one as well — a one percent increase in the propensity for wildfire (as measured by each variable) leads to less than a one percent increase in the propensity for escaped prescribed fire. One would hope that prescribed burners choose to respond to higher risk by increasing precaution in terms of timing and effort so that even when burning in a fire prone environment (where incidentally the benefits of prescribed fire are likely to be higher), a smaller percentage of fire escape and those that do inflict less damage.

Total state land is the total acreage of the state (in thousands of acres). All else constant, more land supports more fires. The elasticity estimates are positive as expected for private land, strongly significant, and in some cases surprisingly large. This could be related to the fact that the smallest states are also in the Northeast, where among the fewest fires occur.

Federal land acreage is the amount of federal land in a state (in thousands of acres).

Holding total state acreage constant, more federal land implies less private land and vice versa, and therefore fewer escaped private prescribed fires but more escapes from federal land. As expected, the estimated elasticities for private land are all negative and significant. In contrast, all but one of the estimated elasticities are positive for the federal land regressions, again as expected. There is no clear theoretical basis for including *Total state land* or *Federal land acreage* and in the average acreage and damage equations, so they are included only in the selection equation of the Heckman sample selection model.

Land value represents the average value per acre of rural private land. To the extent that land value is a proxy for values at risk, a negative sign on the coefficient is expected, because higher values at risk mean higher potential damage, more endogenous precautionary effort, and therefore ultimately higher expected costs of prescribed fire. The estimated effects are mixed however, and weak for federal land. Two factors that might confound the results are that if wildfire risk mitigation is the primary benefit of prescribed fire, prescribed fire might be applied more often where land values are high.

Population density represents the average human population density. Like *Land value*, this variable is included as a proxy for potential damage, so a higher population density represents higher potential damage, with a negative expected sign. The sign is negative and significant at the 10 percent level or better in eight of ten cases, insignificant in the other two cases.

Average farm size (in acres) is a proxy for land ownership fragmentation. Small plots will tend to increase the cost of prescribed fires. On the other hand, if marginal precaution costs tend to be lower per fire, then more precaution ought to be exerted per fire. Therefore, the sign could be either positive or negative. The elasticity is positive in the first private land regression (number of escapes) but negative and strongly significant in the others. The latter negative coefficients could in fact be because even if a fire escapes, where farm sizes are small there are likely to be more fire breaks such as roads, etc. The federal land elasticity estimates are also negative in four of five cases (significant in three). Although private land ownership acreage will directly affect federal land fires that move onto private land, there is likely to be some correlation between the average size of contiguous federal land holding and the size of rural private landholdings.

State forest acreage and *State grass acreage* are estimates of the number of acres (in 1000s) of forest land and grassland, respectively (as defined in section 3), and are included as proxies to control for the extent of predominant vegetation types in the state. If prescribed fire is used mostly to manage non-crop forest or pasture vegetation, then the elasticity estimates on the number of escapes and total acreage and damage should increase. The estimated signs and significance on both of these are mixed. The only consistent pattern is that *state forest acreage* has a positive and significant impact in all federal land regressions. There is no clear theoretical basis for including these variables in the average acreage and damage equations, so they are omitted except in the Heckman selection equation.

Median patch size is a proxy for vegetation fragmentation. If "patchiness" as defined for this variable tends to be associated with more (or more effective) natural or man-made fuel breaks, one might expect that fewer fires would get out of control, or would be smaller in magnitude if they did. The sign of the estimates are mixed.

The *1970-1985 dummy* takes the value 1 if *year* < 1986 and zero if *year* > 1995 (as discussed above, intervening years are left out of the analysis due to missing data). The parameter estimates are not statistically significant from zero for four of five private land regressions, suggesting that there is little substantive difference between the number or extent of escaped debris fires early in the sample as compared to late on private land. It is interesting to note, however, that the estimates for federal land are all positive and strongly significant. this is consistent with the fact that prescribed fire use on federal lands has increased substantially since 1995 (U.S. Department of Interior et al. 2001).

6 Conclusion

Prescribed fire is increasingly viewed as an effective tool for wildfire risk mitigation and vegetation management for biodiversity, game habitat, as well as for timber and agricultural forage production. Nonetheless, the use of prescribed fire is risky, and in many environments increasingly so. Human populations at the wildland-urban interface increase as residential developments extend into forest land, and almost a century of fire suppression and exclusion exacerbate the problem in many places. In fragmented landscapes, escaped prescribed fires and associated liability are major concern.

The empirical analysis in this article finds evidence that different liability and regulatory rules affect the number and magnitude of escaped prescribed fires. *Ceteris paribus*, States with strict liability rules tend to have fewer private land escaped prescribed fires than states with a negligence rule, and those that do escape tend to be smaller and inflict less damage. Further, permits and/or burn bans and criminal penalties for negligence tend to reduce the incidence and extent of escape.

Because state liability law does not directly affect federal employees, however, there should be no systematic effect of state law on the incidence and severity of escaped prescribed fires started by federal employees. The empirical results presented here are generally consistent this hypothesis: there is little discernible effect consistent with theory of state liability law on public employees on federal land. The results do suggest, however, that public employees on federal land tend to respond to state permit requirements and burn bans, as well as state criminal liability law.

It is crucial to recognize that these results, which suggest that higher incidence and severity of escaped prescribed fires occur under less stringent laws, is in no way an indication that more stringent laws are better. As recognized by a number of statutes in southern states, prescribed fires can provide public benefits through mitigation of general wildfire risk and other broad-scale vegetation management benefits. It is plausible that the benefits of increased prescribed fire use outweigh the additional costs of increased prescribed fire at the margin. Unfortunately, the datasets used in this analysis do not allow an analysis of these net benefits. Additional research and data are needed to better understand the tradeoffs associated with prescribed fire use.

Notes

[1]This shift in emphasis was not universal phenomenon even in North America. In some southeastern states — Florida in particular — fire was such a visible and important part of ecosystems and management practices that prescribed fire was never really abandoned (Carle 2002).

[2]Fire suppression may or may not lead to more volatile fire regimes, depending on the nature of the ecological system in question (Keeley et al. 1999, Minnich 1983).

[3]$\rho > 1$ might represent punitive damages.

[4]To be more specific, ρ as an index of stringency does differentiate between differences in operations costs wx^* or expected damage $\rho d(x^*, z)$ among the forms of liability, where x^* represents the chosen level of precaution under a given rule.

[5]The variance of total aggregate damage is $\text{Var}[nd(\cdot)\varepsilon]=(nd(\cdot))^2\sigma^2$.

[6]Recall that the distribution of damage is $d(\cdot)\varepsilon$. Given $d\varepsilon = \delta\pi\varepsilon$, the distribution of $\delta\varepsilon$ can be interpreted as the distribution of potential damage across landholdings.

[7]This is not to say they do not face liability. It is interesting to note, however, that Cleaves et al. (2000) find that for many burn managers in the Federal National Forest System, direct regulations are often perceived as more of a constraint than liability.

[8]Rosemary Thomas, fire management officer for the Bureau of Land Management (`rosemary_thomas@blm.gov`), and Richard Bahr, Fire Use Specialist for the National Parks Service (`dick_bahr@nps.gov` concurred in personal communication that federal prescribed fire managers generally do not concern themselves with state liability law when performing prescribed fires, but generally do abide by permit requirements and burn bans.

[9]An analysis using pre-aggregated dataset based on NIFMID was developed and presented in Yoder (2004). The pre-aggregated dataset provides a breakdown of fire information in terms of general landownership categories for each year up to and state (including those states not including in NIFMID), but it does not provide information about ownership at the fire origin, or the category of people who initiated intentional management ignitions.

[10]Selection of these two samples is based on a set of NIFMID variables: OWNERSHIP_ORIGIN (NIFMID guide table 2.1.4 and 2.2.11), STATISTICAL_CAUSE, SPECIFIC_CAUSE, and PEOPLE (NIFMID guide tables 2.2.2). A wildfire observation is defined to have been an escaped debris fire if STATISTICAL CAUSE = 5, which correspond to fires started for "field burning," "land clearing," and "resource management burning," "trash burning," "burning dump," "slash burning," and "R/W [right-of-way] burning." This broad set of burning activities is included because prescribed fire law is likely to apply to these cases.

[11]These characteristics correspond to OWNERSHIP_ORIGIN = 2 or 3 and PEOPLE = 1, 2, 3, or 5.

[12]These individuals correspond to OWNERSHIP_ORIGIN = 1 or 4 and PEOPLE = 4 or 5.

[13]One factor that supports the use of both types of costs is that a number of state statutes explicitly impose liability on individuals for suppression costs if they negligently allow a fire escape their land.

[14]One exception to the hypothesized effect of *Land value* is that if prescribed fire is used to reduce wildfire hazard such that prescribed fire is used more often, it might lead, ironically, to more escaped prescribed fires.

[15]Poisson distributions are characterized by an equal mean and variance. Overdispersion is the case in which the estimated variance is significantly larger than the estimated mean. Negative Binomial regressions are able to allow for overdispersion; A positive and significant

dispersion parameter estimate α indicates overdispersion.

[16]Van Garderen and Shah (2002) provide an approximation to the exact unbiased estimator of the variance of the dummy-variable transformation. This approximation was used for estimating the standard errors reported in this paper. It is worth noting that the delta method consistently overestimated the variance relative to the finite-sample approximation as predicted Van Garderen and Shah (2002).

[17]Strictly speaking, a PBM law is in effect in Texas, but no burn managers were certified in Texas for the time period covered by this sample due to onerous insurance requirements.

[18]The other legal variables in these regressions are not as consistent as with the larger samples, however. This is likely due to the fact that there is much less variation among these variables in this smaller set of states.

References

American Law Reports Editorial Staff. 1994. "Liability for Spread of Fire, Intentionally Set for Legitimate Purpose." In *American Law Reports Annotations and Cases*, volume 25, 391–567. Rochester, NY: Lawyers Cooperative Publishing. (25 ALR5th 391).

Babbitt, Bruce. 1995. "To Take Up the Torch." *American Forests* 101 (7 and 8).

Brenner, Jim and Dale Wade. 1992. "Florida's 1990 Prescribed Burning Act." *Journal of Forestry* 90 (5):27–30.

—. 2003. "Florida's Revised Prescribed Fire Law: Protection for Responsible Burners." In *Proceedings of Fire Conference 2000: The First National Congress on Fire Ecology, Prevention, and Management.*, eds. K.E.M. Galley, R.C. Klinger, and N.G. Sugihara, volume 90, 132–136. Tallahassee, FL: Tall Timbers Research Station. Miscellaneous Publication No. 13.

Briggs, J.M. and A.K. Knapp. 1995. "Interannual Variability in Primary Production in Tallgrass Prairie: Climate, Soil Moisture, Topographic Position, and Fire as Determinants of Aboveground Biomass." *American Journal of Botany* 82:1024–1030.

Brown, John. 1973. "Toward an Economic Theory of Liability." *Journal of Legal Studies* 2:323–349.

Carle, David. 2002. *Burning Questions: America's Fight with Nature's Fire*. Westport, CT: Praeger.

Cleaves, David A., Jorge Martinez, and Terry K. Haines. 2000. "Influences on Prescribed Burning Activity and Costs in the National Forest System." Technical Report SRS-37, U.S.D.A. Forest Service Southern Research Station.

Cooper, Charles F. 1960. "Changes in Vegetation, Structure, and Growth of Southwestern Pine Forests Since White Settlement." *Ecological Monographs* 30 (2):129–163.

Donoghue, Linda R. 1982. “The History and Reliability of Hte USDA Forest Service Wildfire Reports.” Technical Report NC-226, U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. `http://ncrs.fs.fed.us/pubs/rp/rp_nc226.pdf`.

Greene, William. 2003. *Econometric Analysis*. Upper Saddle River, New Jersey: Prentice Hall, fifth edition.

Haines, Terry K. and David A. Cleaves. 1999. “The Legal Environment for Forestry Prescribed Burning in the South: Regulatory Programs and Voluntary Guidelines.” *Southern Journal of Applied Forestry* 23 (3):170–174.

Hesseln, Hayley. 2000. “The Economics of Prescribed Burning: A Research Review.” *Forest Science* 46 (3):322–334.

Keeley, Jon E., C. J. Fortheringham, and Marco Morais. 1999. “Reexamining Fire Suppression Impacts on Brushland Fire Regimes.” *Science* 284:1829–1835.

Kennedy, Peter E. 1981. “Estimation with Correctly Interpreted Dummy Variables in Semilogarithmic Equations.” *American Economic Review* 71 (4):801.

Kimmerer, Robin Wall and Frank Kanawha Lake. 2001. “The Role of Indigenous Burning in Land Management.” *Journal of Forestry* 99 (11):36–41.

Kolstad, Charles D., Thomas S. Ulen, and Gary V. Johnson. 1990. “*Ex Post* Liability for Harm vs. *Ex Ante* Safety Regulation: Substitutes or Complements?” 80 (4):888–901.

Minnich, Richard. 1983. “Fire Mosaics in Southern California and Northern Baja California.” *Science* 219:1287–1294.

National Interagency Fire Center. 2001. *Prescribed Fire Statistics*. `http://www.nifc.gov/stats/prescribedfirestats.html`. Last accessed, January 18, 2004.

National Resources Inventory. 1997a. "Table 15 - Estimated Median Diameter of Wildlife Habitat Patches on Nonfederal Rural Land in 1997, by Land Cover/Use, by State (Data in Feet)." http://www.nrcs.usda.gov/technical/NRI/1997/summary_report/table15.html.

—. 1997b. "Table 2 - Land Cover/Use of Nonfederal Rural Land, by State and Year (Data Per 1,000 Acres)." http//:www.nrcs.usda.gov/technical/nri/1997/summary_report/table2.html.

NIFMID. 2004a. "National Interagency Fire Managment Integrated Database." http://famweb.nwcg.gov/kcfast/mnmenu.htm.

—. 2004b. "National Interagency Fire Managment Integrated Database (NIFMID) Technical Guide [Draft]."

Pyne, S. J. 1982. *Fire in America : A Cultural History of Wildland and Rural Fire*. Princeton NJ: Princeton University Press.

Pyne, Stephen J. 1991. *Burning Bush: A Fire History of Australia*. New York, NY: Henry Holt and Company.

Roe, Brian. 2004. "Optimal Sharing of Foodborne Illness Prevention Between Consumers and Industry: The Effect of Regulation and Liability." *American Journal of Agricultural Economics* 86 (2):359–374.

Shogren, Jason F. and Thomas D. Crocker. 1999. "Risk and its Consequences." *Journal of Environmental Economics and Management* 37:44–51.

U.S. Census Bureau. 2001. "Annual Population Estimates 1990 to 2000." http://eire.census.gov/popest/data/counties/tables/CO-EST2001-12.php.

—. 2004. "Annual Population Estimates 2000 to 2003." http://eire.census.gov/popest/data/states/NST-EST2003-ann_est.php.

U.S. Census of Agriculture, Agricultural Statistics Database. 2004. "Total Farms, Land in Farms, Average Farm Size." http://www.nass.usda.gov:81/ipedb/.

U.S. Department of Agriculture, National Agricultural Statistics Service. 2003. "Farm Real Estate: Average Value Per Acre, by Region and State." http://www.usda.gov/nass/pubs/histdata.htm.

U.S. Department of Interior et al. 2001. "Review and Update of the 1995 Federal Wildland Fire Management Policy." Technical report. http://www.nifc.gov/fire_policy.

U.S. Department of the Interior, U.S. Department of Agriculture. 1995. "Federal Wildland Fire Management Policy and Program Review, Final Report." Technical report. http://www.fs.fed.us/land/wdfire.htm. Last accessed January 18, 2004.

Van Garderen, Kees Jan and Chandra Shah. 2002. "Exact Interpretation of Dummy Variables in Semilogarithmic Equations." *Econometrics Journal* 5:149–159.

Yoder, Jonathan. 2004. "Effects of Liability and Regulation on Prescribed Fire Risk in the United States." In *2nd Symposium on Fire Economics, Planning, and Policy: A Global View*, eds. Armando González Cabán and Francisco Rodríguez Y Silva. Còrdoba, Spain.

Zimmerman, J.L. 1997. "Avian Community Responses to Fire, Grazing, and Drought in the Tallgrass Prairie." In *Ecology and Conservation of Great Plains Vertebrates*, eds. F.L. Knopf and F.B. Samson, 167–180. New York NY: Springer.

Figure 1: Histograms of debris fire numbers, damage+suppression, and acreage (left side) and all other fires (right side). All variables are in natural log form, observations with values of zero omitted.

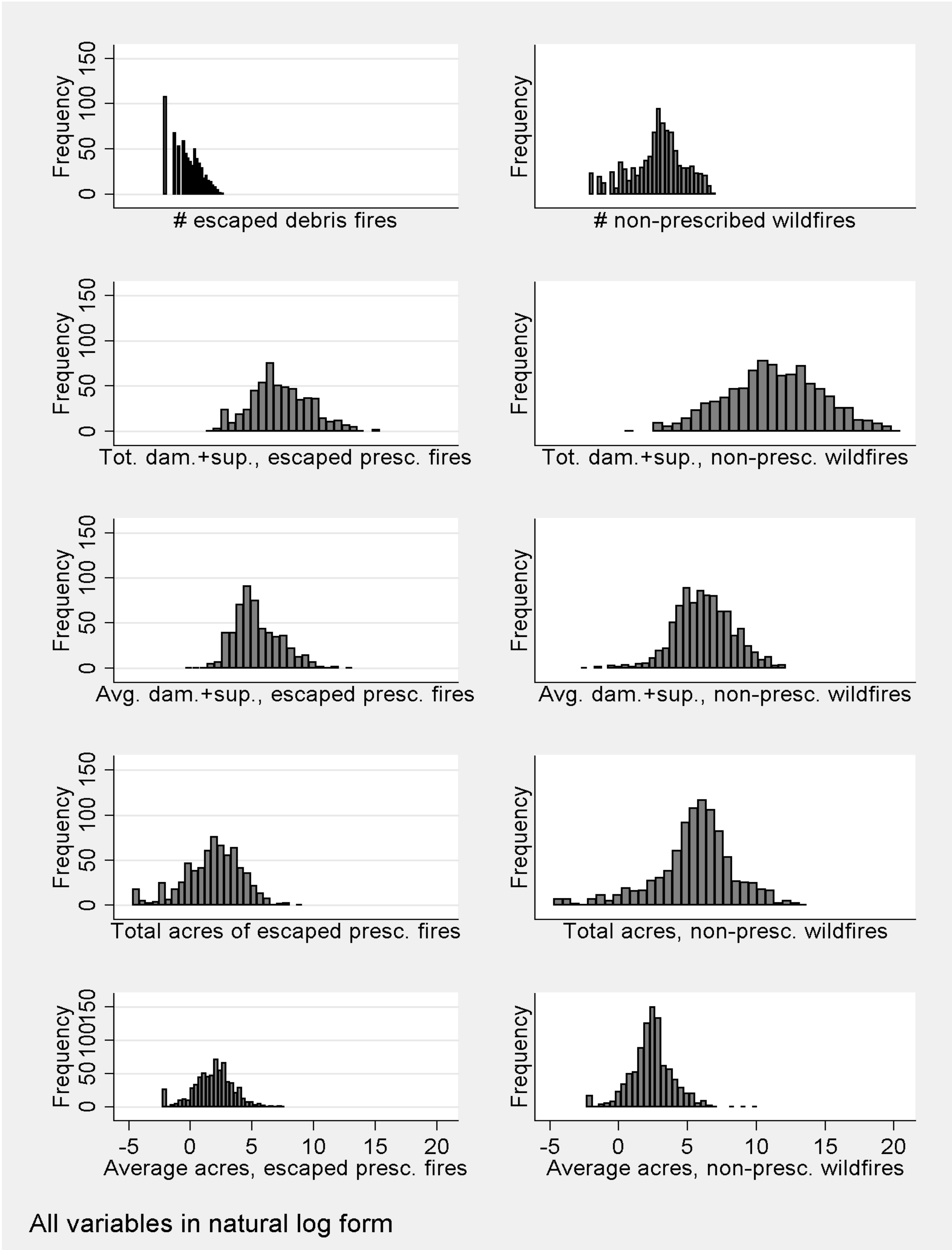

Table 1: State statues for selected prescribed fire laws, 2002

Liability or regulation	State
Burner strictly liability	CT, ND, NH, OK
statutory Permits or bans	AL, AZ, CA, CO, CT, FL, GA, ID, IA, ME, MA, MN, MS, NE, NV, NH, NJ, NY, OR, RI, SD, UT, WV, VT, WA
Criminal penalties for unattended fire or negligent escape	AL, AK, CA, MI, NJ, NM, NV, NC, OK, OR, SC, SD, TN, UT, WI, WY
Prescribed Burn Manager Laws	AL, FL, GA, LA, MS, SC, TX[a]

[a]TX has a Certified Burner law, but no one had been certified as of 2002, arguably due to a difficult-to-satisfy insurance requirement. Therefore, Texas is treated as if it had no Prescribed burn manager (PBM) law.

Table 2: Summary statistics for variables used in regressions.

Variable[a]	Obs	Mean	Std.Dev.	Min	Max
# d. fires	1104	236.198	457.42	0	78
tot. d+s	1104	6078136	305392	0	7760759
tot. ac.	1104	11945.3	59941	0	1004873
avg. d+s	872	10312.0	31777	0	403209
tot. ac.	887	74.6966	881.33	.1	24024
# other fires	1104	5.67934	9.136	0	3074
tot. d+s, oth. fires	1104	35889.3	3.5e+7	0	8.1e+8
tot. acres, oth. fires	1104	144.947	925.5	0	26339.4
avg. d+s, oth. fires	670	5998.44	45114	0	1070221
avg. acres, oth. fires	687	29.9849	120.62	.1	1580.5
strict liability	1104	.093297	.29098	0	1
permits/burn bans	1104	.437	.49630	0	1
criminal penalties	1104	.645833	.47847	0	1
PBM law	1104	.036231	.18695	0	1
PBM gross negligence	1104	.007246	.08485	0	1
total land in state	1104	39.4598	29.663	.669	167.625
federal land acreage	1104	9.56192	14.745	.004	61.548
land value	1104	1051.3	797.85	103.7	4525.17
population density	1104	258.325	364.71	5.34	1809.17
average farm size	1104	687.144	1089.8	83.3	6645.16
state forest acreage	1104	8.38150	6.3437	.305	21.980
state grass acreage	1104	11.2400	18.348	.023	113.45
median patch size	1104	859.833	104.53	590	1000
1970-1985 dummy	1104	.695652	.46033	0	1

[a]Abbreviated to match table 3:
 # d. fires = number of wildfires started as fires;
tot. and *avg.* stand for total and average;
d+s = resource damage plus suppression costs;
ac.=acres; *oth.*=other.

Table 3: Regression results: Elasticities (continuous variables) and percent differences (dummy variables).

	Started on private land					Started on Federal land				
Dependent Variable →	#d.fires	ln(tot.d+s)	ln(tot.ac.)	ln(avg.d+s)	ln(avg.ac.)	#d.fires	ln(tot.d+s)	ln(tot.ac.)	ln(avg.d+s)	ln(avg.ac.)
Strict liability	-0.12***	-0.92***	-0.97***	-0.91***	-0.26	0.01	0.14	-0.20	3.55*	0.42
Permits/burn bans	-0.30***	-0.77***	-0.18	-0.37**	-0.42***	-0.08	0.08	0.35*	0.19	0.18
Criminal penalties	-0.02	-0.59***	-0.75***	0.21	0.23	-0.17***	-0.20	-0.15	-0.39**	-0.44**
PBM law	.004	0.94	2.26	0.14	0.42	0.01	0.82	0.81**	1.98	0.90
PBM gross negligence	.003	-0.79***	-0.96***	0.08	-0.09	0.00	-0.31	-0.62	-0.99*	-0.57
# other fires^{a}	0.48***			0.94^{c}***	0.24^{c}***	0.38***			0.79^{c}***	0.30^{c}***
ln(Tot. d+s, oth. fires)		0.91***					0.27***			
ln(Tot. acres, oth. fires)			0.87***					0.17***		
ln(Avg. d+s, oth. fires)				0.82***					0.69***	
ln(Avg. acres, oth. fires)					0.23***					0.17**
Total land in state^{a}	3.63***	1.86***	1.94***	4.18^{c}***	1.00***	0.27	0.47***	-0.96***	2.72^{c}**	0.71^{c}**
Federal land acreage^{a}	-1.02***	-0.33	-0.31***	-0.11^{c}***	-0.03***	0.10	0.43***	0.62***	0.01^{c}	-0.01^{c}
Land value^{a}	0.96***	-1.63***	-1.14***	-0.73***	0.01	-0.04	-0.26	0.25	0.38	0.69***
Population density^{a}	-1.02***	0.16	-0.62**	-0.19*	-0.16	-1.19***	-0.33**	-0.44***	-1.24***	-0.78***
Average farm size^{a}	0.06*	-2.56***	-1.99***	-0.57***	-0.41***	-0.01	-0.31	0.06	-0.73***	-0.46***
State forest acreage^{a}	-0.18	-0.10	1.72***	-0.45^{c}**	-0.11**	0.72***	0.72***	1.00***	0.92^{c}***	0.23^{c}**
State grass acreage^{a}	-1.27***	-0.01	0.46***	-1.83^{c}***	-0.44***	-0.11	-0.08	0.41***	-0.71^{c}*	-0.20^{c}
Median patch size^{a}	5.93***	3.59**	1.04***	-3.12***	-1.22	1.24**	-1.99**	0.75	-5.53***	-2.92**
1970-1985 dummy	-.004	0.12	5.83***	-0.08	0.45	0.50***	0.53*	0.89***	2.12***	0.96***
Constant	-6.24***	-24.34***	-27.9***	1.41***	14.17	-2.32***	-3.70	-21.53***	60.49***	
Auxiliary parameter^{b}	1.10***	9.80***	4.55***	0.30***	0.85	1.10***	13.56***	6.78***	-0.70***	-0.47***
Regression type	N.B.	Tobit	Tobit	Heck.	Heck.	N.B.	Tobit	Tobit	Heck.	Heck.
Total Obs.	1104	1104	1104	832	832	1104	1104	1104	832	832
Noncensored Obs.	–	564	687	550	550	–	366	464	359	473
R-Sq/Pseudo R-Sq.	0.13	0.17	0.08	0.14	0.13	0.19	0.14	0.12	0.34	0.12

*significant at 10% level; **significant at 5% level; *** significant at 1% level

[a]Natural log used in all but the *#d.fires* regressions.

[b]Equals dispersion param. α for Negative Binomial (N.B.); std. dev. σ for Tobit; corr. coef. ρ for Heckman.

[c]In Heckman selection equation only.

Table 4: Elasticity estimates for legal parameters: Public prescribed fires in western states (USFS regions 1-6), and private contractor fires in southern states (USFS region 8)

Dependent variables →	#d.fires	ln(tot.d+s)	ln(tot.ac.)	ln(avg.d+s)	ln(avg.ac.)
	Fires started on federal land by public employees				
Strict liability	0.02	-0.14	-0.66**	3.03	0.80
Permits/burn bans	-0.29*	0.27	-0.46	-0.61**	-0.51**
Criminal penalties	-0.60***	-0.87***	-0.86***	-0.64***	-0.63***
	Fires started on private land by contractors				
Strict liability	-0.33*	-0.43	-0.56	-0.96***	-0.83***
Permits/burn bans	0.52	4.62	2.79	0.84**	0.30**
Criminal penalties	-1.31***	-0.40	0.12	0.27	0.19
PBM law	-0.16	-0.56**	-0.44**	-0.31***	-0.15***
PBM gross negligence	0.05*	1.87	0.37	-0.10	0.05