Liability, Regulation, and Endogenous Risk: The Incidence and Severity of Escaped Prescribed Fires in the United States

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Abstract

Prescribed fire is a useful but risky method for reducing the general wildfire risk and improving wildlife habitats, biodiversity, timber growth, and agricultural forage. In the past 15 years, laws to further promote the use of prescribed fire have been adopted in several states. This article examines the effect of liability laws 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 laws and regulations tend to reduce the number and severity of escaped prescribed fires on private land but not on federal land, where state liability laws do not directly apply. An economic motivation—based on the explicit recognition in these statutes of the perceived public benefits provided by prescribed fires—for the recent changes in statutory laws is provided.

1. Introduction

Aboriginal Americans used fire extensively to cultivate native grasses, modify forest vegetation, and facilitate hunting. This cultural use in conjunction with the natural occurrence of fire was an important determinant of the ecological landscapes that existed during the European colonization of North America (Kimmerer and Lake 2001; Pyne 1982, 1991). In the early twentieth century, the U.S. federal land management agencies and other related institutions moved away from active use of prescribed fire to focus almost exclusively on fire suppression, a shift in management symbolized by the creation of Smokey 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

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[1] This shift in emphasis was not a 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 use of prescribed fire was never really abandoned (Carle 2002).

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have produced vegetation structures more conducive to large, hard-to-control catastrophic fires (Carle 2002; Babbitt 1995; Cooper 1960).[2]

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. Empirical research increasingly suggests that fire holds unique capabilities for improving biodiversity and agricultural productivity (González-Cabán et al. 2003; Carle 2002; Zimmerman 1997; Briggs and Knapp 1995; Babbitt 1995; Cooper 1960). Pollet and Omi (1999), Omi and Martinson (2002), Prestemon et al. (2001), and other researchers find that the use of prescribed fire can reduce the risk of catastrophic wildfires.

This growing scientific consensus about the usefulness of prescribed fire is being adopted by policy makers as well. The federal government now formally recognizes prescribed fire as an integral element of wildfire management on federal lands (U.S. Department of the Interior 1995). Cleaves, Martinez, and Haines (2000) report that the number of national forest management teams using prescribed fire increased by 76 percent between 1985 and 1994. About 900,000 acres of federal land were treated with prescribed fires in 1995, and the annual acreage treated had increased to 2 million by 1999.[3] The Healthy Forests Restoration Act (16 U.S.C. sec. 6501 [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. The interest on the part of public policy makers and land managers is mirrored by private property owners as well. Loomis, Blair, and González-Cabán (2001) find that property owners in Florida value the use of prescribed fire as a wildfire risk mitigation tool, and private prescribed fire associations such as the Edwards Plateau Prescribed Burning Association are popping up in the southern Great Plains.[4]

Increasing interest in the use of prescribed fire notwithstanding, it is a risky management tool. Stephen Pyne (2001, pp. 2–3), among the most prolific writers on the ecology of fire and its relationship with humans, wrote that "[p]rescribed burning has wracked up an impressive litany of failures. . . . Over the past 20 years the worst fires of several entire seasons have been prescribed fires gone bad." According to him, "[t]he two most costly firefights of American history

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

[3] National Interagency Fire Center, Fire Information: Wildland Fire Statistics (http://www.nifc.gov/fire_info/prescribed_fires.htm).

[4] Loomis, Blair, and González-Cabán (2001), Loomis et al. (2000), and Fried, Winter, and Gilless (1999) find via contingent valuation that individuals express positive willingness to pay for public wildfire risk reduction activities. More generally, quite a few existing articles assess the costs and benefits of prescribed fire use at the level of individual applications. Economic analyses not cited elsewhere in this article include Yoder (2004b), Rideout and Omi (1995), Cleaves and Brodie (1990), and Bernardo, Engle, and McCollum (1988). In addition, Walstad, Radosevich, and Sandberg (1990) references a number of related articles, and Hesseln (2000) reviews the economics literature on prescribed fire published between 1975 and 2000.

were controlled burns that blew up." Because of the potentially high costs of escaped prescribed fires, 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).

In light of these concerns over liability, the resurgence of interest in prescribed fire use is accompanied by new legislation and new regulations in many states. Within the last 20 years, many southeastern states have enacted legislation that explicitly recognizes that careful application of prescribed fire provides public benefits (Haines and Cleaves 1999). These statutes tend to clarify liability standards relative to common law and their statutory precursors. In most cases, they institute more stringent regulations over prescribed fire use, and in some cases they simultaneously reduce the burden of civil liability for burners. In Florida and Georgia, for example, certified burn managers now must satisfy more stringent and detailed preparation and documentation requirements, but they face a gross-negligence standard rather than simple negligence or strict liability for property damage from an escaped prescribed fire (Brenner and Wade 2003).

This article examines the effect of liability laws and related regulations on the incidence and severity of escaped prescribed fires and discusses the normative implications and political economic motivations behind the recent move toward more stringent regulations and weaker liability for burners. The analysis includes a number of contributions to the economic literature on liability and regulation, endogenous risk, and prescribed fires.

First, the article provides the first econometric examination of the effects of laws and regulation on prescribed fire risks, and it provides an example of the effects of liability laws on endogenous risk in natural resource management generally. A set of regressions is estimated to assess the impact of state laws and regulations on escaped prescribed fires. The empirical analysis uses data on individual wildfires for 1970 through 2002 in conjunction with a categorization of state statutory laws pertaining to liability and regulation. The results show that the incidence and severity of escaped prescribed fires originating from private landowners or their agents tend to be lower in states with more stringent statutory liability laws and regulatory restrictions. Public employees using prescribed fire on federal land face federal law that does not vary formally across states, and the results suggest that this group of prescribed burners is not as responsive to state law as private land managers are.[5]

[5] The empirical literature on the effects of liability rules on behavior and risk is growing and, consistent with fundamental theory, generally finds significant effects of law. Examples include Sloan, Reilly, and Schenzler (1995), which examines the effects of liability law and insurance on the incidence of drinking and driving and finds that liability law affects the incidence of binge drinking but had no statistically significant effect on the fraction of binges that were followed by drunk driving. Cummins, Phillips, and Weiss (2001) find that states with no-fault liability insurance have higher fatal accident rates than do states relying on tort liability. There is also a large set of articles relating to medical malpractice liability, including Baicker and Chandra (2004), Kessler and McClellan (1996, 2002), Viscusi and Born (1995), Farber and White (1991), and Danzon (1991); articles on environmental liability include Opaluch and Grigalunas (1984) and others to be discussed below.

Second, the direction of the recent statutory changes elicits a number of questions not yet addressed substantively in the normative literature on the economics of liability and regulation. Interestingly, the movement toward more lenient liability rules for these environmental risks is in contrast to the trend away from negligence and toward strict liability for toxic pollution releases (Alberini and Austin 2002, 1999a, 1999b). This article argues that a potential economic motivation for moving toward weaker liability (specifically, gross negligence) and stronger regulations is in response to increasing recognition of the regional public benefits of prescribed fires in terms of wildfire risk mitigation and wildlife habitat management.

A theoretical model, testable hypotheses, and a normative discussion of the effects of changes and differences in legal and regulatory institutions are developed in the next section. Section 3 examines the normative implications of recent trends in statutory laws, data and estimation methods are described in Section 4, results and interpretations are presented in Section 5, and Section 6 concludes.

2. Liability and Incentives for Precaution

Laws and regulations affect the incentives of individuals for taking risks and for exerting precaution in the process (see, for example, Roe 2004; Kolstad, Ulen, and Johnson 1990; Brown 1973). Thus, for prescribed fire, 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.

Consider a set of heterogenous landowners who benefit from applying prescribed fire on their land but who also face costs and risks associated with its use. Assume that if a prescribed fire escapes, damage is done to the property of a neighbor, and both the burner and the neighbor can invest in precautions to mitigate the damage. Suppose also that there is no evidentiary or judicial uncertainty, neighbors do not contract over prescribed fire risk ex ante, but each agent has complete knowledge of the other's characteristics. Finally, assume that the burner maximizes the private net value of a prescribed burn by choosing a precaution level and performs a burn only if the private net benefit of doing so is positive. The neighbor receives no direct benefit from the burn and minimizes the expected costs of the burner's prescribed burn by choosing precautions.[6]

With no liability and no regulation, the burner would have no incentive to invest in precautions, because all risk of escape is externalized to the neighbor. Suppose instead that the burner faces one of three forms of liability: strict liability, simple negligence, or gross negligence. The expected costs to the burner of performing a fire will be different under each of these forms. Given strict liability,

[6] The possibility that the neighbor benefits from prescribed fire on the burner's land will be discussed later.

the burner always compensates the neighbor for property damage in the event of an escape, and the damage may be excessively great because neighbors have no incentive for self-protection. Under a simple negligence rule, the burner will just satisfy the standard and will not compensate the neighbor, so the neighbor has an incentive to invest in precautions. Both no compensation and neighbor precaution reduce the expected costs to the burner, compared with the situation under strict liability, so more landowners will burn and will burn more often. Under gross negligence, the standard is set lower than it is under simple negligence. The burner will again choose to just satisfy the standard but will exert less effort to do so.[7]

Formally, the ex ante net expected value to a burner (agent b) and the negative of expected costs to a neighbor (agent o) of a prescribed fire are specified as

$$\begin{aligned} V^{\mathrm{b}} &= r - \rho d(\boldsymbol{x}, \boldsymbol{z})\varepsilon - wx^{\mathrm{b}}, \\ V^{\mathrm{o}} &= -(1-\rho)d(\boldsymbol{x}, \boldsymbol{z})\varepsilon - wx^{\mathrm{o}}, \end{aligned} \tag{1}$$

where $r \sim (\bar{r}, \varsigma^2) \in [0, \infty]$ represents the benefits from a prescribed fire that are randomly distributed across land parcels but are known ex ante. The liability stringency index $\rho \in (0, 1)$ is increasing as the legal burden on the burner increases, in the following order: (*a*) gross negligence, (*b*) simple negligence, and (*c*) strict liability.[8] The function $d(\boldsymbol{x}, \boldsymbol{z})$ represents the expected damage from an escaped prescribed fire and depends on endogenous precaution $\boldsymbol{x} = [x^{\mathrm{b}}\ x^{\mathrm{o}}]$ and environmental characteristics $\boldsymbol{z}$. The random disturbance $\varepsilon \in [0, \infty]$ is distributed $(1, \sigma^2)$, and w is the marginal cost of precaution for both individuals. If we assume that sufficient conditions hold, maximizing equations (1) provide precautionary input demands $x^i = x^i(\rho, w, \boldsymbol{z})$ for $i =$ b, o. Comparative statics results for the impact of ρ on precautionary effort by b and o imply that as the stringency of liability increases, the burner increases effort and the neighbor decreases effort given a burn.

Given that effort levels of the two agents move in opposite directions as burner liability increases, the effect of liability stringency on expected damage per escape depends on the relative productivity of x^{b} and x^{o}. Burners have crucial control over both the likelihood of escape and the potential extent of the damage through their choice of when to burn (Roberts, Engle, and Weir 1999). One illustration of this is a tough trade-off: the most risky environment to burn in (hot, dry, lots of vegetation) is also often the most productive burning environment. If a burner chooses to burn under these circumstances for effectiveness, a burn is

[7] When evidentiary uncertainty exists, as in Shavell (1984a) and Kolstad, Ulen, and Johnson (1990), the result is less clear, but gross negligence is nonetheless likely to reduce a burner's expected costs relative to those associated with simple negligence.

[8] The following definitions for these terms suffice for the purposes of this article. Strict liability is liability for harm regardless of the level of precaution. Simple negligence is failure to use a level of precaution that a reasonable person would use under the circumstances. Gross negligence is conduct or a failure to act that demonstrates willful or reckless disregard for the safety or property of another.

not only more likely to result in escape, but it is also likely to result in more damage and higher suppression costs than would result from an escape that occurs under more benign (cooler, less windy) conditions. Furthermore, negligence standards as applied by courts often hinge on the degree of preparation that burners apply prior to a prescribed fire (American Law Reports 1994), such as the creation of fire breaks and having sufficient labor and suppression equipment around to snuff out unintentional flare-ups and spot fires that may occur.

Neighbors have unique access to their own property and can manage the risk of wildfires by managing their own vegetation surrounding their valuable property, so they might be more effective at reducing damage on their land once a fire has arrived. However, neighbors may not even be aware ahead of time that a burn is going to be performed, and this situation can limit certain types of ex ante precautions. Furthermore, apart from removing portable property or performing ex ante risk mitigation, it is often not the neighbor but professional firefighters who mitigate property damage. Although most property owners are covered for wildfire damage to their property through standard insurance policies, liability insurance for the application of prescribed fire is often very difficult to acquire. These facts strengthen the incentives of burners relative to those of neighbors for mitigating risk.

Finally, strict-liability and negligence rules for burners have a long history in the law (American Law Reports 1994). If neighbors had effective control over risk and burners had little, then it would make more sense for neighbors to be the primary bearer of risk instead of transferring it to burners through liability rules.

All things considered, burners are likely to have more control over the likelihood and the extent of damage than are neighbors. Given this restriction on the general model, a number of testable hypotheses follow.[9]

Hypothesis 1. Fewer prescribed fires will escape under more stringent burner liability rules.

Hypothesis 2. Damage per escape will be lower under more stringent burner liability rules.

Because aggregate damage is the product of the number of escapes and the average damage per escape, hypotheses 1 and 2 taken together suggest the following additional hypothesis:

Hypothesis 3. Aggregate damage from escaped prescribed fires will be lower under more stringent liability rules.

In summary, hypotheses 1–3 imply that there will be fewer and less damaging escaped fires in states with simple negligence rules than in states with gross-

[9] Formal comparative statics results from the model are available in Yoder (2005).

negligence rules, and still fewer and less damaging fires in states with strict-liability rules.

In addition to tests about the effects of civil liability rules, the effects of direct regulation and criminal liability are examined. Regulatory permit systems that restrict the number and timing of prescribed fires in order to limit their risks will tend to lead to fewer escaped prescribed fires and less damage from wildfires originating as prescribed fires. Burn ban statutes allow states and counties within states to restrict the use of prescribed fire during certain times of year and/or certain conditions, usually when weather conditions are conducive to extreme wildfire risks or severe smoke nuisance problems. The implementation of these two regulatory instruments varies across states. Some permit systems act primarily as a notification requirement to local environmental, resource, or firefighting agencies. Others attach permit-specific restrictions based on current local conditions that may address smoke nuisance and/or wildfire risks, and some require written plans (prescriptions) before burning (Haines and Cleaves 1999; Craig 1990). In states where burn bans are supported by state statutes, they are usually implemented at the county level by county administrators. Thus, for these regulatory approaches, there tends to be substantial administrative flexibility within the statutory context of a state.

A number of states also have statutes imposing criminal penalties for leaving a prescribed fire unattended and/or for negligent escape. For example, in Tennessee, it is a class B misdemeanor to leave a fire unattended whether or not it escapes (Tenn. Code Ann., sec. 39-14-305 [2008]), and in Wyoming, it is a misdemeanor with a penalty of up to $750 and/or 6 months in prison for criminal negligence in allowing a fire to damage another's property (Wyo. Stat., sec. 6-3-105 [2008]). There is some variation in terms of criminal penalties across states, and although it is difficult to assess the value associated with potential prison time, the magnitudes of financial penalties are in all cases very small relative to the potential for civil damages associated with an escaped prescribed fire. If we assume that these regulatory restrictions and criminal penalties are designed to reduce the number of escapes and the magnitude of damage given an escape, the following straightforward hypothesis follows:

Hypothesis 4. Regulatory restrictions and criminal penalties reduce the incidence and severity of escaped prescribed fires.

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. Therefore, strictly speaking, variations in state liability laws 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 setting provides a basis for another testable hypothesis:

Hypothesis 5. State liability laws 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 federal employees not facing state laws 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 laws ought not in principle have an effect on the behavior of federal employees on federal land, direct state regulatory restrictions may have an effect.[10]

Other nonlegal, nonregulatory factors also affect the use of prescribed fire and precaution during use. These are factors that affect the size of the benefits, r, elements of $\boldsymbol{z}$ (from equation [1]) that affect the size of the 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. The proxy variables used in the regressions to represent these factors will be discussed in sections 4 and 5, but an example of an element of $\boldsymbol{z}$ 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 wildfires that were not started as prescribed fires.

3. Motives for Statutory Change

Recent statutory laws for prescribed burning in a number of southeastern states simultaneously impose among the strictest regulatory standards and the most lenient liability standards in the country. The laws are designed such that if the regulatory requirements for burning are satisfied, then gross negligence must be shown by the plaintiff to extract damages in a civil suit (Brenner and Wade 2003). This section focuses on an economic motivation for this shift toward weaker negligence rules and stricter regulatory rules. To proceed, a further examination of the literature on optimal liability standards and the joint use of regulation and liability is in order.

There is a large literature on optimal liability standards and the optimal choice among a wide array of liability rules. However, little existing literature characterizes gross negligence in economic terms, but a few recent working papers apply. Ganuza and Gomez-Pomar (2004) and Dari-Mattiacci (2004) arrive at a standard below simple negligence as a second-best mechanism when facing the problem of judgement-proof injurers. Schäfer (2003) finds a negligence standard below simple negligence to be a second-best response given judicial uncertainty. These findings are intriguing with respect to the applicability of soft negligence

[10] Rosemary Thomas, fire management officer for the Bureau of Land Management, and Richard Bahr, fire use specialist for the National Parks Service, concurred in telephone conversations (August 2004) 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.

rules in isolation but provide little insight regarding the joint use of regulation and soft liability rules.

Several motivations for the joint use of liability and regulation have been suggested in the literature, and there is no apparent consensus yet on the relative importance of each. For example, Shavell (1984a, 1984b) suggests that the joint use of regulation and liability might be justified in settings with variations in potential harm, judgment proofness, and the possibility of escaping suit. Kolstad, Ulen, and Johnson (1990) argue that joint use is optimal given ex post evidentiary uncertainty about precaution, and Schmitz (2000) argues that variation in the wealth of injurers is sufficient for joint use of liability and regulation to dominate. Despite their disparate underlying assumptions, one particular relationship between liability and regulation emerges from all of these models. Schmitz (2000), Shavell (1984a), and Kolstad, Ulen, and Johnson (1990) all find that joint use is likely to entail a lower regulatory standard than when ex ante regulation alone is used. Interestingly, in the case of many environmental hazards, including prescribed fire, liability through common law has apparently been the temporal forerunner to regulation in dealing with prescribed fire risks (American Law Reports 1994). This fact begs a different set of questions than that addressed by Shavell (1984a), Schmitz (2000), and Kolstad, Ulen, and Johnson (1990): when, if ever, should liability standards be set lower in conjunction with (stronger) regulation than without it? This question has apparently not arisen in the literature on the joint use of liability and regulation, and the institutional environment surrounding prescribed fire provides a hint at one possible answer.

In fact, a motivation for the shift toward weaker liability and more stringent regulation is virtually explicit in a number of the statutes themselves, which are often called right-to-burn laws. Florida's law, for example, states explicitly that prescribed fire provides public benefits in terms of wildfire risk mitigation and wildlife habitat through its effects on vegetation.[11] In light of these perceived public benefits, the statutory changes could be viewed as an attempt to induce more burning by reducing the expected costs to burners of performing prescribed fires while still providing incentives for precaution by both burners and their neighbors.[12]

As support for this view, suppose that all precautionary activities were initially subject to simple negligence, but regulation was then introduced such that one set of precautionary activities is explicitly regulated with efficient regulatory

[11] In the southern Great Plains, prescribed fire is often used for killing woody invasive species such as the eastern redcedar. Given the characteristic spread of invasive species, this activity provides positive externalities in terms of invasive-species management (Bernardo, Engle, and McCollum 1988).

[12] Sun (2006) also examines the distribution of liability laws across states but does not discuss the public benefits (positive externalities) of vegetation management.

standards and one set is addressed by a lower negligence standard.[13] With no uncertainty about either set of standards, this arrangement reduces the precaution costs of the burners because the gross-negligence standard is satisfied with less precaution. If the burner faces uncertainty about the ex post liability standard but not the ex ante regulatory standard, then the burner's exposure to damage risk is different under the two rules as well. Expected damages are not zero for a given level of precaution under a negligence rule but are zero under a regulation. Therefore, replacing liability with regulation of a subset of precautionary activities is likely to reduce the expected costs to burners of an escaped fire.[14] For these two reasons, the shift toward more substantive regulation and reduced liability standards will tend to reduce burners' costs of burning. As is clearly the hope of the drafters of the right-to-burn laws in the Southeast, this cost reduction will in principle increase the amount of prescribed fire used in these states to bolster the weak incentives of burners to burn.

The costs that are shifted away from burners do not disappear, of course; they are shifted onto neighbors, who will bear more risk associated with any prescribed fire on nearby land. Neighbors will therefore have an incentive to bear additional precaution costs. This result may hint at a comparative advantage of using gross negligence to promote the use of a risky behavior that provides other related public benefits. Prescribed fire for risk mitigation is simply fire under control or a wildfire waiting to happen. As such, the level of prescribed fire risk is likely to be positively correlated with wildfire risk generally. Therefore, neighbor risk mitigation (especially through vegetation management) provides public benefits for the same reason that prescribed burning itself does (in fact, a burner's neighbor could be a burner too). Thus, shifting the risk of prescribed fire to a neighbor provides a multiplier effect for private wildfire risk mitigation that would otherwise have to be addressed by additional instruments such as regulations or subsidies for vegetation management.[15]

[13] Some elements of precaution are better suited for ex ante regulation, and some elements are better suited for liability rules. For example, in Florida an approved written burn plan is required prior to burning, and a certified burner (having passed an approved course) must be present until the fire is extinguished. Various weather parameters for carrying out the burning must be specified in the burn plan, but obviously not all contingencies can be covered specifically. These unspecified margins would be subject to gross negligence if all regulatory restrictions are met. Shavell (1984b) and virtually all others assume only one precaution subject to both liability and regulation. However, precaution for any risky activity can usually take many forms, and regulation viewed as an ex ante contract is always incomplete. The multi-input case is used here simply to emphasize this relatively unexplored perspective (a recent exception is Innes [2004], who mentions multidimensional precaution only in passing).

[14] Schmitz (2000), Kolstad, Ulen, and Johnson (1990), and Shavell (1984a) suggest for various reasons that optimal regulatory standards should be lower when used in conjunction with liability than when used without it. This suggestion might imply that regulatory standards should be set higher with gross negligence than with simple negligence. Doing so would act to offset the cost differences somewhat, but in principle these standards would still be set lower than an efficient simple negligence standard, so this offsetting effect is likely to be relatively weak.

[15] The relative efficacy of this approach for accounting for the public benefits of prescribed fire is up for debate. One particularly interesting approach is that of public nuisance. Although nuisance claims for smoke from prescribed fires are commonplace, nuisance claims for the wildfire risk due

Table 1
State Statues for Selected Prescribed Fire Laws, 2002

Liability or Regulation	State
Burner strictly liable	Connecticut, North Dakota, New Hampshire, Oklahoma
Statutory permits or bans	Alabama, Arizona, California, Colorado, Connecticut, Florida, Georgia, Idaho, Iowa, Maine, Massachusetts, Minnesota, Mississippi, Nebraska, Nevada, New Hampshire, New Jersey, New York, Oregon, Rhode Island, South Dakota, Utah, West Virginia, Vermont, Washington
Criminal penalties for unattended fire or negligent escape	Alabama, Alaska, California, Michigan, New Jersey, New Mexico, Nevada, North Carolina, Oklahoma, Oregon, South Carolina, South Dakota, Tennessee, Utah, Wisconsin, Wyoming
Prescribed burn manager laws	Alabama, Florida, Georgia, Louisiana, Mississippi, South Carolina, Texas

Note. Texas has a certified burner law, but no one had been certified as of 2002, arguably because of a difficult-to-satisfy insurance requirement. Therefore, Texas is treated as if it had no prescribed burn manager law.

4. Data and Estimation

Several regressions are developed to estimate the impact of legal, environmental, and demographic factors on the number and severity of escaped prescribed fires. The data used in this analysis come from a number of sources: data on fire characteristics are from the National Interagency Fire Management Integrated Database (NIFMID), and variables representing state-level laws and regulations were constructed from state statutes and verified through cross-referencing with other published sources and telephone conversations with agency employees. The characteristics of the data led to the use of dynamic negative binomial, Tobit, and sample-selectivity models. This section begins with a data description and follows with a discussion of estimation methods.

Table 1 shows state statutory laws. There are a great many subtle differences in statutory liability laws for prescribed fire across states, but this analysis focuses only on the two fundamental forms, strict liability and negligence rules. Most states with statutory laws relating to prescribed fire explicitly specify a negligence rule. In the absence of a 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 1994). Four states—Connecticut, North Dakota, New Hampshire, and Oklahoma—however, impose

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to poor vegetation management in fire-prone areas is uncommon. A small number of states, such as Washington, have statutory laws imposing a negligence rule for leaving timber slash after harvest in such a way as to increase the risk of wildfire (see, for example, Wash. Rev. Code Ann., sec. 76.04.660 [2005]). However, no statutes yet address risks that follow from unmanaged natural vegetation growth. These examples illustrate that liability is more readily applied to cases in which discrete action rather than inaction is involved in an increase in risk. Nonetheless, Bakken (1997) provides an interesting discussion of the potential nuisance risk faced by land managers for excessive fire danger and suggests that this risk may be substantial.

strict liability on prescribed burners at various times in the sample time frame. If a fire escapes, the burner is liable for damage regardless of his or her effort to contain the fire.[16]

Permits and fire bans can be interpreted as regulatory attempts at reducing the number of high-risk prescribed fires. It turns out that there is a near one-to-one match between the states with statutes that support permits and the 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. Furthermore, the potential inter- and intrastate variations in the way burn bans, permit systems, and criminal penalties are administered was noted earlier, and care should be used to interpret these effects as average conditional effects of a heterogeneous set of incentive instruments. The potential effects of prescribed burn manager (PBM) laws are more complex. These laws tend to reduce the stringency of liability that PBMs face, but they do so only if the PBMs satisfy a relatively strict set of guidelines. In Florida and Georgia for the latter years of the panel, PBMs are liable if found grossly negligent as long as they have met an explicit set of regulatory conditions. If the explicit regulatory conditions have not been met, they face a more stringent simple-negligence standard.[17]

Descriptions and summary statistics of variables used in the estimations are presented in Table 2. Fire data come from the National Interagency Fire Management Integrated Database (NIFMID), which includes approximately 380,000 observations on individual fires from 1970 through 2002 for all states except Connecticut, Hawaii, Iowa, Massachusetts, Maryland, New Jersey, and Rhode Island.[18] The states with data 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.[19] The data descriptions that follow rely on the NIFMID *Technical Guide* (USDA Forest Service 1998). In addition to an incomplete set of states, the NIFMID has almost no data on escaped debris fires (and other categories of human-caused 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 1970–85 and

[16] Sun (2006) has developed a different categorization of state liability laws. Further discussion is provided in Section 5.

[17] Nevada has a gross-negligence law that applies only to state employees, and Michigan instituted gross negligence as of 2005 (Sun 2006).

[18] For the National Interagency Fire Management Integrated Database (NIFMID), see National Wildfire Coordinating Group, KCFAST—Kansas City Fire Access Software, Fire Occurrence Information Retrieval (http://famtest.nwcg.gov/fam-web/kcfast/html/ocmenu.htm).

[19] An analysis using a preaggregated data set based on the NIFMID was developed and presented in Yoder (2004a). The preaggregated data set provides a breakdown of fire information in terms of general land ownership categories for each year and state (including those states not included in NIFMID), but it does not provide information about land ownership at the fire's origin or the category of people who initiated intentional management ignitions.

Table 2
Summary Statistics

Variable	Mean	SD	Minimum	Maximum	Number of Observations
Number of P fires	5.609	9.158	0	78	1,008
Total D + S	31,960	271,641	0	7,800,000	1,008
Average D + S	4,072	14,747	0	241,831	612
Number of other fires	232.3	450.6	0	3074	1,008
Total D + S, other fires	5,700,000	35,000,000	0	809,000,000	1,008
Average D + S, other fires	10,239	32,375	0	403,209	795
Strict Liability	.093	.291	0	1	1,008
Permits/Burn Bans	.646	.478	0	1	1,008
Criminal Penalties	.417	.493	0	1	1,008
PBM Law	.036	.186	0	1	1,008
PBM Gross Negligence	.008	.089	0	1	1,008
Total Land in State	39.46	29.67	.669	167.6	1,008
Federal Land Acreage	9.561	14.75	.004	61.55	1,008
Land Value	1,066	795.4	103.7	4,447	1,008
Population Density	258.5	364.6	5.475	1,809	1,008
Average Farm Size	687.8	1,088	83.33	6,645	1,008
State Forest Acreage	8.381	6.343	.305	21.98	1,008
State Grass Acreage	11.25	18.35	.024	113.5	1,008
Median Patch Size	859.8	104.5	590	1,000	1,008

Note. D + S = resource damage plus suppression costs; PBM = prescribed burn manager; P fires = escaped prescribed fires.

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

Data from the NIFMID relate to wildfires generally. For a wildfire started as a prescribed fire, the data pertain to wildfires that occurred outside the prescription, not including the acreage originally in the prescription. That is, all observations used in this analysis pertain only to the escaped component of a prescribed fire. Per the NIFMID definitions, a relevant prescribed 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."[20] A prescribed 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 National Forest boundary" and by a "public employee" or "local permanent."[21] Although not perfect categorizations, these definitions fit as closely as possible given the data definitions.

There are a number of weaknesses associated with the NIFMID. 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 (U.S. Department of Agriculture Forest Service form FSH 5109.14), and the data requested are in some cases not defined very clearly. Furthermore, the

[20] These characteristics correspond to the NIFMID variables OWNERSHIP_ORIGIN = 2 or 3 and PEOPLE = 1, 2, 3, or 5.

[21] These individuals correspond to the NIFMID variables OWNERSHIP_ORIGIN = 1 or 4 and PEOPLE = 4 or 5.

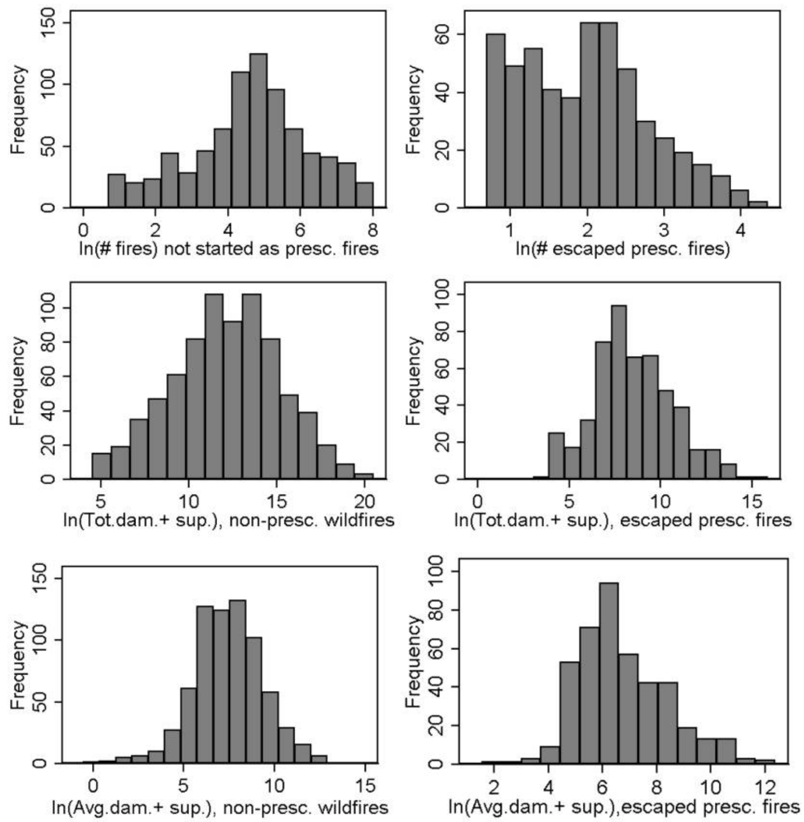

Figure 1. Histograms for all wildfires (*left*) and escaped prescribed fires (*right*)

requested data are in some cases omitted. To the extent that data omissions or misinterpretations affect independent variables or are otherwise systematic, additional bias might be introduced into the regression estimates.

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

The general wildfire risk will have an important effect on both the risks associated with using it and the usefulness of prescribed fire. This baseline risk is dependent on the characteristics of the vegetation and environment in which a prescribed fire occurs, and, 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 of wildfires, the total resource damage, and the average damage plus suppression costs are shown in Figure 1 (note that observations with values of zero are omitted).

The value of rural land is dependent largely on the value of the productivity of that land. The crops, timber, forage, and other vegetative output represent, in this case, potential damage from an escaped prescribed fire. Therefore, Land Value ($1,000s per acre deflated by the national consumer price index) is used as one proxy for potential damage from an escaped prescribed fire.[22] Average Farm Size (in acres) is available from the U.S. Department of Agriculture's Economics, Statistics, and Marketing Information System.[23]

The land cover type affects the propensity for prescribed fire use as well as wildfire risk and severity. These data from the National Resources Inventory (NRI) span 1982–97, with observations every 5 years.[24] Data were interpolated linearly between data points for annual estimates and were set to the 1982 and 1997 values for the years before and after, respectively. State Grass Acreage is the sum of the acreage of the NRI variables Pasture Land and Range Land, and State Forest Acreage is the NRI variable Forest Land. Median Patch Size is the estimated median diameter in feet of wildlife habitat patches (it is right censored at 1,000 feet) and proxies for vegetation fragmentation.[25]

The human population density is included as an additional proxy for potential damage, because larger human populations are associated with more residential and business structures and more health risks from escaped fires. Increases in either of these variables are hypothesized to reduce the number of escaped prescribed fires. Population estimates for 1970–2002 were compiled from U.S. Census Bureau intercensal data tables (U.S. Census Bureau 2001, 2004). Population Density was estimated by dividing the population for each year by the total land area of the state as reported in the NRI.

Two separate samples of escaped prescribed fire observations are selected from the NIFMID for comparison: 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 on the basis of the aggregated data.[26]

[22] For land values, see National Agricultural Statistics Service, Agricultural Land Values and Cash Rents—Final Estimates (http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID = 1519).

[23] For average farm size, see National Agricultural Statistics Service, Number of Farms and Land in Farms (http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID = 1709). One exception to the hypothesized effect of Land Value is that if prescribed fire is used to reduce the wildfire hazard such that prescribed fire is used more often, it might lead, ironically, to more escaped prescribed fires.

[24] See U.S. Department of Agriculture, Natural Resources Conservation Service, 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).

[25] See U.S. Department of Agriculture, Natural Resources Conservation Service, 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).

[26] Selection of these two samples is based on a set of NIFMID variables: OWNERSHIP_ORIGIN (USDA Forest Service 1998, tables 2.1.4 and 2.2.11), STATISTICAL_CAUSE, SPECIFIC_CAUSE, and PEOPLE (table 2.2.2). A wildfire observation is defined to have been an escaped debris fire if

The dependent variables used in the regressions are the number of escaped prescribed fires in a given state and year, the aggregate total estimated damage plus suppression costs incurred in a state and year, and the average of damage plus suppression costs per escaped fire in a state and year. The sum of the estimated resource damage plus suppression costs is used to represent the total costs of escapes because the two are endogenously determined: for a given wildfire environment, more suppression leads to less damage.[27] Note that these dependent variables correspond directly to hypotheses 1–5.

For each of the regressions, a set of annual dummy variables is included to capture changes in technology, broad weather patterns, and other factors that are changing over time but not captured by other regressors; thus, the regressions are fixed-effects panel data models with time-specific fixed effects. A lagged dependent variable is also included in each regression to capture dynamic relationships from one year to the next.[28] The formulas for the elasticities and marginal effects shown below correspond to the contemporaneous impact of a variable on the dependent variable.[29]

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. 740–44).[30]

Aggregate damage plus suppression costs from escaped prescribed fires is zero when no escaped prescribed fires are recorded for a given state and year, an occurrence that is not uncommon. Therefore, a Tobit regression is applied to account for censoring. Given annual intercept dummy variables, the regression model can therefore be characterized as

$$Y_{it} = \max\,[0,\ \alpha_t + \boldsymbol{\beta X}_{it} + \lambda Y_{it-1} + \varepsilon_{it}], \tag{2}$$

STATISTICAL CAUSE = 5, which corresponds to fires started for “field burning,” “land clearing,” “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 laws are likely to apply to these cases. Thus, the term “prescribed fire” used in this article corresponds to the term “debris fire” in the NIFMID definitions.

[27] 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 to escape their land.

[28] In panel data models with a lagged dependent variable and cross-sectional fixed effects, standard fixed-effects models provide inconsistent estimators, which leads to various approaches such as the Arellano-Bond estimator (for a discussion, see Cameron and Trivedi 2005, pp. 764–65). When fixed effects are time specific, this problem does not arise.

[29] Long-run equilibrium impacts are not reported in the tables, but for the linear index models considered here, the following regression relationship holds: $h(y_{it})(1 - \lambda L) = \boldsymbol{\beta}'\boldsymbol{x}_{it} + \varepsilon_{it}$, where L is a lag operator. The partial effects can be written as $\partial h(y_{it})(1 - \lambda L)/\partial \boldsymbol{x}_{it} = g(\boldsymbol{\beta}'\boldsymbol{x}_{it})$. When dividing through by $(1 - \lambda L)$ and assuming a long-run equilibrium, the long-run effect is $\partial h(y_{it})/\partial \boldsymbol{x}_{it} = g(\boldsymbol{\beta}'\boldsymbol{x}_{it})/(1 - \lambda)$.

[30] Estimated short-run elasticities for the negative binomial regression based on an exponential mean function are $\varepsilon_i^{\mathrm{nb}} = (y_i/\boldsymbol{x}_i)\boldsymbol{\beta}\exp(\boldsymbol{x}_i'\boldsymbol{\beta})$. Long-run elasticities can be calculated as $\varepsilon_i^{\mathrm{nb}}/(1 - \lambda)$, where λ is the coefficient for the lagged dependent variable on the right-hand side of the regression.

where $t = 1, \ldots, T$, $i = 1, \ldots, n$, and ε_{it} are assumed independently and identically distributed normally distributed random variables.[31]

All nonbinary variables are transformed to natural logs before estimation because the estimated disturbances in the preliminary regressions appeared to be approximately lognormal for the noncensored observations.[32] Log transformations cannot be performed when a variable takes the value of zero (the natural log of zero is $-\infty$). Values of zero were changed to .0001 prior to taking the logarithm. The lower bound for the dependent variable in the Tobit model as estimated is therefore $\ln(.0001) \approx -9.21$.

When there are no fires in a state in a given year, the average damage is undefined, and many of the same factors that affect the average damage (given at least one escape) affect the chance of at least one escape occurring. Ignoring this sample selectivity process can result in biased parameter estimates. Therefore, a Heckman sample selection model is estimated for the average damage equation.[33] In these regressions on the average damage per fire, each observation represents an average over all of the escaped debris fires in that state and year. Thus, the variance of the sample averages will diminish with the number of escapes in a given state and year. This fact is accounted for in the regressions by performing weighted maximum-likelihood estimation. 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 data set.[34]

5. Results

Table 3 presents results for two sets of regressions. The first set corresponds to prescribed fires that were started on private land, and the second set corre-

[31] Honoré (1993) develops an alternative to Tobit for estimating a dynamic fixed-effects model given a censored dependent variable and a lagged value on the right-hand side. Given Honoré's (1993) Monte Carlo experiment results and the structure of the present panel and model, it is unlikely that this approach would be an improvement over the dynamic Tobit model in terms of the mean squared error. The standard Tobit approach is therefore used.

[32] Short-run elasticities for an observation i of a nonbinary variable in the Tobit regressions are $\varepsilon_{it}^{\text{tob}} = \partial E[\ln(y_{it}) \mid \boldsymbol{x}_{it}]/\partial \ln(\boldsymbol{x}_{it}) = \boldsymbol{\beta}\Phi(\boldsymbol{\beta}'\boldsymbol{x}_{it}/\sigma)$. The long-run elasticity is $\varepsilon_{it}^{\text{tob}}/(1-\lambda)$. Building on Kennedy (1981), the short-run percentage difference corresponding to one dummy variable $\boldsymbol{d}_j \in \boldsymbol{D}$ under normally distributed disturbances is $\varepsilon_{it}^{\text{tob},d} = \Delta E[\ln(y_{it}) \mid \boldsymbol{x}_{it}, \boldsymbol{D}_{it}]/\Delta d_j = [\exp(\beta_j - .5v_j) - 1]\Phi(\boldsymbol{\beta}'\boldsymbol{x}_i/\sigma)$, where Δd_j is 1 or -1 and v_j is the variance of the dummy variable coefficient β_j. Van Garderen and Shah (2002) provide an approximation to the exact unbiased estimator of the variance of the dummy variable transformation. The long-run elasticity is $\varepsilon_{it}^{\text{tob},d}/(1-\lambda)$.

[33] The estimated short-run elasticity vector from a Heckman sample selection model with nonbinary variables in natural log form is $\varepsilon_{it}^{\text{heck}} = \partial E[\ln(y_i) \mid \text{in sample}]/\partial \ln(\boldsymbol{x}_i) = \boldsymbol{\beta} - \boldsymbol{\gamma}\beta_\lambda\delta_i(\boldsymbol{w}_i'\boldsymbol{\gamma})$, where $\boldsymbol{x}$ and $\boldsymbol{\beta}$ are the matrix of explanatory variables and vector of parameters in the second-stage regression of interest and $\boldsymbol{w}$ and $\boldsymbol{\gamma}$ are the variables and parameters in the selection equation, and $\delta_i = \lambda_i(\lambda_i - \boldsymbol{w}_i'\boldsymbol{\gamma})$, where $\lambda_i = \phi(\boldsymbol{w}_i'\boldsymbol{\gamma})/\Phi(\boldsymbol{w}_i'\boldsymbol{\gamma})$ is the inverse Mills ratio evaluated at observation i. Although not explicit in the notation above, nonbinary variables in $\boldsymbol{w}$ are in natural logs. For the percentage change due to dummy variables, the Kennedy (1981) transformation is applied, and the long-run elasticity is calculated as $\varepsilon_{it}^{\text{heck}}/(1-\lambda)$.

[34] All estimation and graph generation was performed using the statistical software Intercooled Stata, version 9.3.

Table 3

Regression Results

	Started on Private Land			Started on Federal Land		
	Number of P Fires	ln(Total D + S)	ln(Average D + S)	Number of P Fires	ln(Total D + S)	ln(Average D + S)
Strict Liability	−.85**	−.86**	−.94**	.19	.61	7.50+
Permits/Burn Bans	−.18*	−.69**	−.57*	−.05	.15	.01
Criminal Penalties	−.03	−.39	−.08	−.18+	−.04	−.54
PBM Law	.25	.92	.33	.32	.89	.90
PBM Gross Negligence	.62*	−.86	−.99	.26	−.48	−.23
Number of other fires[a]	.31**		1.33**[b]	.25**		1.60**[b]
ln(total D + S, other fires)		.81**			.17**	
ln(average D + S, other fires)			.81**			.55**
Total Land in State[a]	2.15**	1.63*	5.56**[b]	.35	−.08	2.15[b]
Federal Land Acreage[a]	−.70**	−.65*	−.15**[b]	.02	.41**	.01[b]
Land Value[a]	.64**	.88	−.40	.41+	1.30**	−.29
Population Density[a]	−.85**	−.49	−.06	−1.15**	−.70**	−.88**
Average Farm Size[a]	.07*	−1.28**	−.28*	−.05	.39+	−.91**
State Forest Acreage[a]	−.19+	−.21	−.42+[b]	.51**	.87**	1.12**[b]
State Grass Acreage[a]	−.78**	.04	−2.37**[b]	−.11	.19	−.50[b]
Median Patch Size[a]	4.67**	5.25**	−1.96*	2.03**	−1.01	−7.10**
Lagged dependent variable	.42**	.21**	.22**	.18**	.03**	.05
Constant[c]	−5.07**	−109.95**	37.6**	−3.73**	−115.0*	83.41**
Auxiliary parameter	.73+	9.80**	−.09	.77**	13.31**	−.31*
Regression type	NB	Tobit	Heckman	NB	Tobit	Heckman
Total observations	1,008	1,008	705	1,008	686	688
Noncensored observations		505	423		322	215

Note. The auxiliary parameter equals the dispersion parameter α for a negative binomial model, SD σ for a Tobit model, and correlation coefficient. The R^2/pseudo-R^2-value for fires started on private land is .20, and the R^2-value for fires started on federal land is .17. D + S = resource damage plus suppression costs; NB = negative binomial; PBM = prescribed burn manager; P fires = escaped prescribed fires.

[a] The natural log was used in all regressions but those for the number of fires.

[b] These values were statistically significant in the Heckman sample selection equation only.

[c] Year dummies were jointly significant in every regression but were omitted from the table. The base year (constant) is 2002.

+ Statistically significant at the 10% level.

* Statistically significant at the 5% level.

** Statistically significant at the 1% level.

sponds to prescribed fires that were started on federal land by public employees. The dependent variables for each set are the number of escaped prescribed fires (P fires), the total damage and suppression costs (total D + S), and the average damage and suppression costs (average D + S). The parameter estimates correspond to elasticities for continuous variables and the percentage differences for binary explanatory variables. The first five rows of independent variables in Table 3 are dummy variables representing state-prescribed fire laws and regulations. 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 are proxies for state characteristics that affect the risks associated with prescribed fire. The final five 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).

For private land, Strict Liability has an estimated negative effect on the number and severity of prescribed fires, and the effects are significant at conventional levels for all regressions. On the basis of the regression for the number of escaped prescribed fires, states with strict-liability rules are estimated to have 85 percent fewer escapes (corresponding to the estimate of −.85 in the first row of the first regression in Table 3). In marginal terms based on sample means, strict-liability states tend to have 1.39 fewer escaped prescribed fires per year and 1.67 fewer fires in a long-run equilibrium than do comparable states with negligence rules.[35] On the basis of sample medians, strict-liability states tend to have 1.83 fewer escaped prescribed fires per year. Compared with the summary statistics, presented in Table 2, this is a substantial proportion of the aggregate average of 5.6 escapes per year per state.

On the basis of the regressions for the natural log of the total D + S, strict-liability states have an estimated 86 percent lower rate of damage plus suppression. The marginal effect of Strict Liability on the unconditional expected value of D + S evaluated at the sample means is \$−55,009 per year; at the sample medians, the effect is a reduction of only about \$3,982 per year.[36] From the regressions for the natural log of the average D + S, we can see that individual escapes lead to an estimated average reduction of \$3,469 in damage and suppression costs, or a reduction of \$406 per escape, based on sample medians. The striking difference between the marginal impacts at sample means and medians reflects the substantial skewness in the fire variable distributions.

The estimated effects of Permits/Burn Bans are negative and statistically significant in all private-land regressions. When evaluated at the sample means, point estimates suggest that states with burn bans and/or permits have on average .41 (18 percent) fewer escaped prescribed fires and \$22,201 (69 percent) less in damage and suppression costs. It should be recognized that the regulatory implementation of permits and burn bans varies substantially across states, so the estimated effects should be interpreted with care.

Criminal Penalties represents states with laws that impose criminal penalties for negligent prescribed burning. The elasticity estimates for the private-land regressions are all negative but statistically insignificant at conventional levels. Private individuals seem to react less to criminal penalties than to civil liability and permits and/or burn bans. This finding could be a reflection of the fact that

[35] Results of regressions with the lagged dependent variables omitted are generally consistent with the estimated long-run effects based on Table 3 estimates. For example, the implied long-run percentage impact of a strict-liability law on the number of fires compared to simple negligence is $\varepsilon^{nb}_{strict}/(1 - \lambda) = -.85/(1 - .42) = -1.46$. With the lagged dependent variable omitted, the estimated percentage impact is −1.26. Such similarities apply broadly across comparable regressions.

[36] Log transformation of ln(total D + S) requires zeros to be changed to an arbitrarily small positive number. The value used for the results in Tables 3 and 4 was .0001. When this value is changed to .01, the largest differences are in the private Tobit regression for ln(total D + S). The legal estimates become, in order, −.93**, −.82**, −.48, .89, and −.46, compared to −.86**, −.69*, −.39, .92, and −.86, respectively (where single and double asterisks indicate statistical significance at the 5 and 1 percent levels, respectively). Overall, it appears that the censoring point of the smaller magnitude used for the presented results provides more conservative results, but the results are qualitatively robust to these changes.

criminal penalties are likely to be much less onerous financially than are civil lawsuits.

In the private-land regressions, the parameter estimates for prescribed burn manager laws—PBM Law and PBM Gross Negligence—are both contrary to hypotheses 1–3 and are statistically insignificant in all but one case. The only parameter estimate associated with these two variables that is either statistically significant or of the expected sign is the effect of gross negligence on the number of fires. These laws in particular pertain to a small set of southeastern states in relatively recent years and apply to only a small 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.

State law often does not, strictly speaking, apply to federal employees, and the results presented in Table 3 for public employees on federal land are strikingly different from those for private land. Thirteen of 15 law-related parameter estimates are statistically insignificant, and 10 of 15 have an unexpected sign. These results are consistent with hypothesis 5.[37] The exception is the parameters associated with Criminal Penalties, which are all negative and in two of five cases statistically significantly so.

Because a vast majority of federal land is in the western states, separate regressions were run for western states, U.S. Forest Service Regions 1–6, only.[38] Table 4 provides a synopsis of the results pertaining to legal variables. Because no PBM laws or gross-negligence laws apply to western states, these two variables were omitted from the regressions.

In contrast to the results shown in Table 3, the Permit/Burn Ban estimates are now all negative, though statistically insignificant. The results for Criminal Penalties notwithstanding, state liability laws and regulations appear to have a very different and weaker effect on federal employees than on private individuals. It is interesting to note that Cleaves, Martinez, and Haines (2000) find that for many burn managers in the Federal National Forest System, direct regulations are often perceived to be more of a constraint than a liability. Although the results for federal employees are weak, the results in Tables 3 and 4 taken together appear to be consistent with these findings of Cleaves, Martinez, and Haines (2000).

[37] The strict-liability parameters in the regressions shown in Table 3 are each based on only one strict-liability state (represented by 23 annual observations each). The only state with a strict-liability rule in the six U.S. Forest Service regions used for the western state public-land regressions is North Dakota. Given that only one state represents strict-liability effects, it is perhaps especially likely that the effects of these dummies may be picking up unrelated state-specific idiosyncrasies. However, the western state results above also hold qualitatively (and are similar quantitatively) if Oklahoma—another strict-liability state—is included in the western state public-lands regressions. It is also noteworthy that neither of the strict-liability states has much federal land. Presumably the federal land ownership variables in these regressions control for this fact sufficiently well.

[38] Forest Service Regions 1–6 include North Dakota, South Dakota, Nebraska, Kansas, Montana, Wyoming, Colorado, New Mexico, Idaho, Utah, Arizona, Washington, Oregon, Nevada, and California.

Table 4
Elasticity Estimates for Western and Southern States

	Fires Started on Federal Land by Public Employees			Fires Started on Private Land by Private Contractors		
	Number of P Fires	ln(Total D + S)	ln(Average D + S)	Number of P Fires	ln(Total D + S)	ln(Average D + S)
Strict Liability	.44	1.80	.38	−.08**	4.26	−.99
Permits/Burn Bans	−.34	−.70	−.60	.05	4.56	.78
Criminal Penalties	−1.08**	−.66	−.69**	−.40+	.38	.08
PBM Law				−.05*	−.39*	−.24*
PBM Gross Negligence				.40	.31	−.14

Note. Sample sizes range from 271 to 273. The data cover public prescribed fires in western states (U.S. Forest Service Regions 1–6) and private-contractor fires in southern states (U.S. Forest Service Region 8). Additional control variables were omitted from the table. D + S = resource damage plus suppression costs; PBM = prescribed burn manager; P fires = escaped prescribed fires.
+ Statistically significant at the 10% level.
* Statistically significant at the 5% level.
** Statistically significant at the 1% level.

Recall that the results of the regressions for PBM Law and PBM Gross Negligence, presented in Table 3, show weak and counterintuitive results. To date, all of the new-generation prescribed fire statutes pertaining to PBMs are located in southern states (see Table 1). Given this regional phenomenon, regressions were estimated using a sample representing only escaped fires started on private land by contractors in southern states, defined as those states in U.S. Forest Service Region 8.[39] The legal parameter estimates for these regressions are presented in Table 4.

The variable PBM Law is hypothesized to have a negative sign, because these laws tend to impose substantial requirements for preparation and precaution. The coefficient estimates are all negative and statistically significant at the 5 percent level. Thus, even though contractors need not necessarily be certified and thus are not necessarily covered by these laws, the results from this more narrowly focused sample suggest that PBM laws reduce the incidence and extent of damage from prescribed fires. It is argued above that PBM laws (right-to-burn laws) were designed to decrease the costs of burning while providing incentives for care. Note that the smallest effect of the PBM Law dummy is in the regression for the number of escaped prescribed fires and amounts to a 5 percent decrease in the number of fires (−.05); the rest of the responses are larger percentages: a 39 percent reduction in total damage and a 24 percent reduction in average damage per fire in states with PBM laws. These results taken together are consistent with a simultaneous decrease in both the endogenous probability and the severity of an escape and an increase in the number of prescribed fires

[39] U.S. Forest Service Region 8 includes Virginia, North Carolina, South Carolina, Georgia, Florida, Kentucky, Tennessee, Mississippi, Alabama, Louisiana, Oklahoma, and Texas. Strictly speaking, a prescribed burn manager law is in effect in Texas, but because of the onerous insurance requirements, no burn managers were certified in Texas for the time period covered by this sample.

set. An opposite directional change in the probability of escape and the number of fires would lead to a muted effect on the number of escapes relative to the damage per escape. Thus, these results are consistent with the apparent intent of these laws: to promote burning while promoting safety.

The coefficient estimates on the variable PBM Gross Negligence are positive in two of three cases but are not statistically significant. However, when the lagged dependent variable is omitted for the southern states (Table 4), the estimation gains 26 observations in the panel, and the gross-negligence parameters are all positive and statistically stronger. It is also interesting to note that criminal penalties, which show such a strong effect for federal employees in the West, do not seem to be of pivotal concern for private burn managers in the South.[40]

The variables directly below the legal variables in Table 3 control for the general propensity for wildfire occurrence and its severity. These variables are different for each regression. The number of other fires (fires other than prescribed fires) is included in the number of P fires regression to control for the general propensity in a state-year for fire ignition, ln(total D + S, other fires) is included in the ln(total D + S) regression to control for the general propensity of damage and supression costs in a state-year, and ln(average acres, other fires) is included in the ln(average D + S) regression to control for the general fire size characteristics in a state-year. In each regression, the corresponding variable is positive and statistically significant. Notably, each of these elasticity parameter estimates are also less than one—a 1 percent increase in the propensity for wildfire (as measured by each variable) leads to less than a 1 percent increase in the propensity for escaped prescribed fire. Burners appear to respond to higher risk by increasing precautions 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 fires escape, and those that do inflict less damage.

The elasticities for Total Land in State are all positive for private land, strongly statistically significant, and, in some cases, surprisingly large. These findings could be related to the fact that the smallest states are also in the Northeast, where among the fewest fires occur. If total state acreage is held constant, more federal land acreage implies that there is less private land (and less federal land acreage implies that there is more private land) and, therefore, fewer escaped private prescribed fires but more escapes from federal land. The estimated elasticities

[40] Ordinary least squares (OLS) results that ignore the limited characteristics of the dependent variables also provide results similar to those in Tables 3 and 4. For example, if OLS is applied to the specification for the natural log of the number of fires in Table 3, the percentage impact of Strict Liability is −.56, which is slightly lower than the negative binomial estimate of −.85. Similarly, for ln(total D + S), an OLS regression leads to a percentage impact of Permits/Burn Bans of −.57, compared to −.69 with the Tobit model. Thus, the OLS parameter estimate is attenuated toward zero, compared to the Tobit estimate, as is to be expected from theory, but beyond that, the results appear quite robust. Similar comparisons show the robustness of each regression. There are a few sign changes, but these are almost universally for parameters with low statistical significance. In some cases, the results even provide stronger support for the hypotheses presented in this article.

for fires started on private land are all negative and statistically significant. In contrast, all estimated elasticities are positive (one statistically significantly so) for the federal land regressions.

Land Value and Population Density are proxies for potential damage but are also often correlated with land tenure characteristics such as parcel size and land use type. Greater potential damage induces more endogenous precautionary effort and, therefore, higher expected costs of prescribed fire, but if wildfire risk mitigation is the primary benefit of prescribed fire, prescribed fire might be applied more often where land values are high in order to reduce wildfire losses (see Yoder [2004b] for more discussion on this type of risky trade-off). The estimated effects of these variables are mixed for Land Value, but the signs on Population Density are negative in every equation and are statistically significant at the 10 percent level in four of six cases.

Average Farm Size is a proxy for land ownership fragmentation. Small plots tend to increase the cost of prescribed fires. The elasticity is positive in the first private-land regression (number of escapes) but negative in the others. The latter negative coefficients could have resulted because even if a fire escapes, where farms are small there are likely to be more fire breaks such as roads. The elasticity estimates for fires started on federal land are negative in three of five cases (and statistically significant in two). Median Patch Size is included to control for vegetation fragmentation. If "patchiness" as defined for this variable tends to be associated with more (or more effective) natural or human-made fuel breaks, one might expect that fewer fires would get out of control or would be smaller in magnitude if they did. The signs of the estimates are mixed.

State Forest Acreage and State Grass Acreage are included as proxies to control for predominant vegetation types. If prescribed fire is used mostly to manage noncrop forest or pasture vegetation, then the elasticities on the number of escapes and total acreage and damage should increase. However, when state acreage is held constant, the parameters represent a comparison with a catchall category of other land cover types, so it is not clear what to expect even qualitatively. The estimated signs and statistical significance on both of these variables are mixed. The only clear pattern is that State Forest Acreage has a positive and significant impact in all federal land regressions.

Finally, annual dummy variables were included to capture broadscale changes over time. The dummy variable for 1970 is omitted, so the intercept corresponds to 1970. The estimates associated with the other annual dummy variables are omitted from Table 3, but they are jointly significant at $p \leq .013$ for each regression.

The considerable robustness of the general pattern of results under different specifications is discussed in the footnotes. Two additional sets of results further indicate robustness. First, wildfire acreage is often used by the wildfire management and suppression community as a proxy for wildfire severity and damage. Regressions exactly analogous to the D + S regressions were performed with total acreage and average acreage as dependent variables. Although these regression results are omitted from this article, the results are very similar qualitatively to the D + S regression results and uniformly support the empirical conclusions reported here.[41]

Second, Sun (2006) has also categorized prescribed fire liability laws but arrived at different liability categorizations for some states. Although the differences in categorizations are debatable owing to the often ambiguous nature of statutory laws, supplementary regressions were run after recategorizing several states in line with Sun's method. There are complications with this comparison, because Sun provides only a snapshot of statutory laws as of 2005, whereas the present analysis contains a panel. Further, Sun included an additional category, uncertain liability, which the present analysis does not include. Nonetheless, for this comparison several states were recategorized in several ways with care to recognize that a number of state statutes had changed between 2002, which is the end of the sample used in this article, and Sun's 2005 sample. In the end, there were no substantive qualitative differences in the regression results as compared to those in Tables 3 and 4. In summary, the general pattern of results holds up well under different specifications, and in a number of dimensions these reported results are among the more conservative of alternative specifications.

6. Conclusion

Prescribed fire is increasingly viewed as an effective tool for wildfire risk mitigation and vegetation management for biodiversity, game habitat, and timber and agricultural forage production. Nonetheless, the use of prescribed fire is risky, and in many environments it is 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 have exacerbated the risk in many places. In economically fragmented landscapes, escaped prescribed fires and their associated liability are a major concern.

This empirical analysis provides 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 escaped prescribed fires from private land than do states with negligence rules, and those fires 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. In many cases, these estimated effects are quite large—such as an estimated 85 percent decrease in escaped prescribed fires due to the imposition of strict liability over negligence and an estimated average reduction of 70 percent in total damage from permits and burn bans. These are surprisingly large responses, but it should be recognized that the vast majority of the inputs and costs of using prescribed fire are applied to reduce the risk of escape (otherwise,

[41] Escaped acreage results are presented in Yoder (2005), and other supporting specification results are available from the author on request.

prescribed fire is essentially just lighting a match). The factors affecting the private risks of escape are likely to affect behavior relating to prescribed fire on private land.

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

Recent statutory changes in many southeastern states represent a shift toward weaker liability for burners, accompanied by more stringent regulation. As has been argued in this article, this change is likely to shift the costs of burning (both input costs and risks) away from the burner. Because of this, the new statutes embody one of a number of possible policy approaches to account for evolving perceptions about the public benefits of prescribed fire, but this approach is particularly well suited for this setting. Because of the close relationship between wildfire risk and the risks associated with prescribed burning, weakening liability for escaped prescribed fire tends to increase the incentives for all landowners to manage the risks of private wildfire, an activity that ostensibly provides positive externalities to the region as a whole.

In light of this general hypothesis about the motivations for the legal and regulatory changes in the Southeast, it is interesting to note that the stricter regulatory restrictions of the right-to-burn laws reduce the number of prescribed fires by only an estimated 5 percent, on the basis of a targeted sample of contract fires, but reduce the total damage by escaped fires much more substantially. Although the data do not allow for a direct estimate of the effect on the amount of burning being done, it is likely that this difference in percentages results because the changes in the law are inducing more prescribed burning, which will tend to offset the reduction in the hypothesized decrease in the fraction and magnitude of escapes due to increased precaution.

The statutory changes in the southeastern states have not yet occurred west of the Great Plains, and it is unclear whether these same trends will expand farther westward. Various important differences—including the extent of public land management, the interconnectedness of public and private lands, and substantially different fire ecology regimes that arguably include a general tendency in the West for larger, harder-to-control wildfires—exist between these regions. Increasingly complex wildland-urban interfaces in the West may induce a regulatory shift toward other vegetation management tools, such as mechanical thinning, instead of a shift toward further promotion of prescribed fire.

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