The Consequences of Wildfire Liability for Firm Precaution: Evidence from Power Shutoffs in California*

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This paper examines firm responses to the entire distribution of potential liability by studying power line-ignited fires in California's electric utility sector. In this setting, when a power line-ignited fire damages a structure, the owner of the power line assumes the cost. The unique setting allows me to estimate how firm precautions vary across the entire distribution of liabilities they face. Using exogenous variation in firms' expected liabilities from potential fire ignitions across days, I show that, on average, firms are 0.03 percentage points more likely to take costly precautionary actions as the level of expected liability that they face increases by 10% (mean of 0.6%). Applying a back of the envelope calculation suggests that, at its mean distribution circuit, the most responsive firm increases precautionary investments by $10 per dollar increase in its expected liability. Furthermore, I show that firms' precautionary responses weaken as the likelihood of bankruptcy from expected liability increases. Applying the estimates to a stylized model implies that limiting firms' exposure to liability across their service territory would create aggregate social welfare benefits between $27 million and $270 million. *JEL* Codes: D22, Q40, L51, K13.

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Low probability, high severity events such as oil spills or product defects characterize many sectors of the U.S. economy. A popular approach to mitigate the frequency of such events is to make firms liable for potential damages in part to incentivize precaution. To understand the effectiveness of liability regulation we need to know how firms' precautions respond to changes in the amount of damages they are liable for.

In settings where a firm faces large potential liabilities from an accident, its liability cannot exceed its asset value because it may use bankruptcy to avoid further damages. This discrete drop in firms' incentives for precautions at their asset value is commonly termed the judgment-proof problem (Shavell 1986). One common solution used to solve the judgment proof problem is to define a negligence standard, or minimum required level of precaution, which incentivizes precautionary investments while limiting bankrupcy risk. However, determining the stringency of the negligence standard is a difficult task for a regulator: more stringent standards of care induce firms to undertake greater precautions as they bear a larger share of liability costs, but setting the standard too stringently may cause the firm to declare bankruptcy, shifting liability costs onto the public. Without a clear understanding of how firms' precautionary investments change across the full distribution of expected liabilities they face, regulators cannot effectively balance precautionary incentives against bankruptcy risk when setting a negligence standard.

Motivated by this gap in the literature on liability regulation, this paper provides the first causal evidence of how firms' precautions responds to the imposition of a negligence standard in California's electric utility sector. Between 1999 and 2017, firms faced with covering liabilities due to power line fires were allowed to recoup these costs through increases in retail electricity prices. However, since November 2017, utilities have borne liability costs whenever the regulator found that their imprudence led to an ignition. Using this setting, I estimate an empirical model that shows how firms' use of one type of precaution, called a Public Safety Power Shutoff event, changed following the policy shift. The empirical model uses daily variation in the replacement cost of structures that would be affected by a potential power line-ignited fire to estimate how firms' use of power shutoffs respond to the entire distribution of expected liability. Since firms in this setting are responsible for the replacement cost of structures damaged by power line-ignited fires, variation in potentially affected regions across days creates exogenous changes in expected liability.

Firms use Public Safety Power Shutoff events to prevent fire ignitions along their power lines.

During a power shutoff, utilities turn the power off on sections of their energy infrastructure when forecasted climate conditions suggest an ignition is likely to occur. Because electricity must be running through a power line for an ignition to happen, power shutoffs significantly reduce the likelihood of fire and potential liabilities that a firm faces. In contrast, other types of precaution available to firms such as clearing vegetation away from power lines do not provide the same assurance because an ignition could still occur.

Firms face significant, time-varying operational costs related to shutoff events. I use one important component of operational costs, the cost of line inspections, to measure how expected liability affects whether firms' declare more costly shutoffs. Prior to restoring electricity service, firms must inspect lines to ensure that there is no contact with vegetation which would cause an ignition once power is restored. When a firm already has many miles of power lines shut off, the demand for inspection resources increases, causing firms to use more costly inputs such as helicopters or drones for inspections and extending shutoff durations which further increases other operational costs. I separately examine how firms' low-cost (few miles of line already shut off) and high-cost (many miles of line already shut off) shutoff use varies with expected liabilities. According to Shavell 1986, firms should make increasingly costly precautionary investments as the expected liability they face increases.

This is an important setting to study liability regulation. Climate change is increasing the severity of power line-ignited fires in the western U.S., making it important to understand how to incentivize firms to prevent ignitions in this setting (Syphard and Keeley 2015). Furthermore, power line-ignited fires are more damaging than fires from other ignition sources because they typically occur during high wind speed events when the wind carries vegetation into the line. Since fires are also more likely to spread rapidly and grow out of control during windy conditions, power line-ignited fires tend to cause more damage than fires from other sources (Keeley and Syphard 2018). For example, one privately owned utility, Pacific Gas and Electric, faced over $30 billion dollars in liability from several fires ignited in 2017 and 2018.[1] Figure 1 plots total damages in billions of 2021 dollars by source of fire ignition and shows that, although power line-ignited fires make up less than one percent of ignitions historically, they account for most of the damage from

1. Los Angleles Times "Pacific Gas and Electric to file for bankruptcy as wildfire costs hit $30 billion. Its stock plunges 52%", January 14, 2019.

fires in California between 2008 and 2019.

This setting also has a key advantage: it allows me to causally estimate the relationship between the expected liability a firm faces and its precaution using exogenous changes in expected fire spread across days.[2] Prior work has typically relied on regulatory changes that implement a specific negligence rule to study this relationship, but in this setting I am able to measure firms' responses across the full distribution of potential liabilities that they face.

Using administrative data on precautionary measures taken by the three largest privately owned utilities in California, I find two results. First, I show that, on average, firms' precaution is positively related to the level of expected liability that they face. Since utilities are liable for the cost of replacing structures damaged by fires that their power lines ignite, I measure liability using this value. In most settings, causal estimation of the relationship between the level of liability that firms face and precaution is difficult because liability is likely to be endogenous. My setting allows me to remove this endogeneity by using a state-of-the-art computational model of fire spread called Elmfire to simulate the change in regions affected by a potential power line-ignited fire across days. I estimate that, on average, firms are 0.03 percentage points more likely to declare a relatively costly power shutoff in response to a 10 percent increase in expected liability (on average, power shutoffs occur on 0.6% of days between 2018 and 2020). In contrast the mean firm is equally likely to declare a low-cost power shutoff as expected liability increases, providing support for theories of firm response to liability documented in prior work.

Second, I demonstrate that firm precautions at the mean circuit do not continue to increase with liability when circuit-level expected liability exceeds 0.08% of firms' total asset value, providing empirical support for the judgment proof problem.

After applying my baseline estimates to a stylized model of firms' precautionary investments to prevent fire ignitions, I find that decreasing expected liability at each circuit would increase short-run aggregate welfare by between \$27 and \$270 million, depending on consumers' valuation of their lost electricity use during a power shutoff.

These results have several policy relevant implications. I provide an empirical framework to estimate how firms' precautionary behaviors change across the distribution of expected liability, a

2. The privately owned utilities in California's electric utility industry that I study are representative of most electric utilities in the United States. In fact, in 2017 privately owned utilities supplied 72% of electricity customers in the United States (EIA Annual Electric Power Industry Report).

key parameter for determining negligence rule stringency. Current and past policy proposals have included limits on the amount of damages homeowners can recover from electric utilities.[3] However, such policy proposals note that it is unclear how the negligence rule's design would distribute costs between homeowners, electricity consumers, and utility shareholders.

This paper makes three contributions to the literature in public economics. First, I show how precaution varies across the distribution of expected liabilities that firms face. Previous research has estimated how limiting medical liability impacts doctors' prescribing behavior (Helland, Lakdawalla, Malani, and Seabury 2021), medical outcomes (Danzon, 1985; Kessler and McClellan, 1996; Currie and MacLeod, 2008; Frakes, 2013), and the labor supply of doctors (Malani and Reif, 2015; Kessler, Sage, and Becker, 2005; Klick and Stratmann, 2007; Matsa, 2007). Another related literature examines how changes in liability impact toxic waste discharges and abatement technology adoption (Akey and Appel, 2021; Alberini and Austin, 2002; Stafford, 2002). Finally, Yoder (2008) shows that the number of fires escaping from private landowners' property during a prescribed burn declines following the implementation of strict liability regulations. Many of these studies estimate how precaution responds to the level of liability a firm faces at one point in the liability distribution because their treatment variation comes from negligence standards which mandate a particular level of care. The empirical strategy in this paper allows me to estimate how precaution changes across the entire distribution of liability that firms face in practice.

Second, it provides evidence that firms' use of costly precautionary investments plateaus at the highest ratios of expected liability to asset value they face. This adds to previous work documenting the role of bankruptcy firms' choice of precaution (Shavell 1986) among other determinants such as subjective firm beliefs (Currie and MacLeod 2014), risk aversion (Shavell 1982), and market structure (Chen and Hua 2017).

Previous work on the judgment-proof problem by Boomhower (2019) shows that requiring firms to purchase insurance which covers damages beyond their own assets encouraged greater production by larger firms with better environmental outcomes in Texas' oil and gas sector. This paper complements Boomhower (2019) by studying a sector with concentrated market power and low likelihood that a firm would permanently exit the market following bankruptcy. Because

3. "Allocating Utility Wildfire Costs: Options and Issues for Consideration", California Legislative Analysts Office, 2019.

monopoly investor owned utilities are the sole service provider for over 70% of electricity consumers in California, the government will not allow the firms to permanently exit the market following bankruptcy. Instead, regulators negotiate with the firm through bankruptcy proceedings, passing liability costs in excess of firm asset value on to tax payers as demonstrated in Pacific Gas and Electric's 2019-2020 bankruptcy proceeding. This regulatory environment may exacerbate the judgment proof problem by allowing firms to remain in the market while also shifting responsibility for extreme liabilities to taxpayers, diminishing incentives for precaution. On the other hand, this regulatory setting may lead firms to invest more heavily in precautionary investments because they have future profit incentives associated with post-bankruptcy operation. Understanding how firms respond to liability in this nuanced context is informative for similar settings such as the market for financial services.

The rest of this paper proceeds as follows: section 1 provides background on liability regulation for power line-ignited fires in California and utilities' ignition prevention decision environment. Section 2 presents a conceptual framework with testable predictions of liability regulation's effect on utility's precautionary effort. Section 3 develops an empirical strategy to causally estimate the relationship between liability and shutoffs. Section 4 describes the data sources used in this analysis, section 5 presents the results, and section 6 concludes and suggests opportunities for future research.

1 Background

1.1 Institutional Background

This paper focuses on electricity distribution to residential and commercial consumers, the final link in the U.S. electricity supply chain which consists of generation, transmission, and distribution.[4] Electric distribution utilities are generally considered natural monopolies and most are regulated by Public Utility Commissions (PUCs). The California Public Utility Commission (CPUC) mandate states that its goal is to provide "...access to safe, clean, and affordable utility services and infrastructure."

4. According to the CPUC post-event reports, transmission lines account for less than 1% of lost customer hours related to power shutoffs to prevent fire ignitions. Therefore, I exclude transmission lines from the analysis in this paper.

PUCs' primary regulatory tool to influence utilities' actions is called a rate case. CPUC defines rate cases as quasi-judicial "proceedings used to address the costs of operating and maintaining the utility system and the allocation of those costs among customer classes." At each rate case proceeding, the PUC determines the electricity price schedules which a utility can charge customers until its next rate case proceeding. The three largest Investor Owned Utilities (IOUs) in California each have their own separate rate cases every three years. In this way, most transmission and distribution utilities in the U.S. face price cap regulation with periodic adjustment of the cap. The PUC adjusts the price schedule so that each utility earns a fair rate of return on its capital and recovers its operating expenses. However, the PUC may disallow a capital expense from being included in the retail price if it does not meet a standard of being "used and useful."

Importantly, in California utilities could request to recover uninsured costs associated with fires ignited by their distribution infrastructure during rate cases between 1999 and 2017. Thus, while utilities paid for residential damages and suppression costs associated with fires ignited by their equipment, they expected to recover these costs through an increase in the electricity price cap. After a 2017 ruling in a rate case proceeding that rejected San Diego Gas and Electric's application to recover fire-related costs through electricity rates, utilities faced a greater likelihood that they would be financially accountable for such costs, increasing their expected liability. The next section discusses the history of fire liability for utilities in California.

1.2 Liability Regulation in California

Liability regulations impact the incentives for individuals and firms to take risk and exert precaution. In the case of fire ignited by utility-operated infrastructure, utilities may adjust their level of precaution according to the proportion of fire-related damages they would be held accountable for if an ignition occurs. Similarly, individual homeowners may increase effort to reduce the probability of wildfire-related damage to their property when a firms' share of liability from a power line ignited wildfire is low. Regulators choose the degree of liability that a firm faces by choosing from two types of regulations: strict liability and a negligence rule. Under strict liability, the firm is fully liable for the resulting damages of a fire ignited by their equipment. In contrast, the negligence rule sets a minimum threshold of precaution that firms must meet in order to avoid financial responsibility for damages. In the canonical model, the firm will take the highest level of precaution under strict liability and reduce its level of ignition prevention to just meet the threshold when subject to the negligence rule (Kaplow and Shavell 1999).

In California, the state has held IOUs to a strict liability standard for fire damages since a 1999 state supreme court decision, *Barham v. Southern California Edison Company (1999).* A key factor in the Court's decision was the fact that, just as a government can raise revenue through taxes, IOUs can raise revenue through retail electricity rates in California.[5] The Court reasoned that since the state government is strictly liable for damages it causes under the Takings clause of the California constitution, IOUs could be held strictly liable for damages related to power line-ignited fires. As a result, IOUs faced strict liability for fire damages in excess of their insurance coverage, but could recover these costs through increases in the retail price of electricity. IOUs continued to challenge the Court's ruling in *Barham* as recently as 2012, arguing that they could not have the same liability status as a government because their ability to raise rates is subject to the approval of the CPUC.[6] The Court continued to maintain, however, that because there was no evidence CPUC would not allow IOUs to recover costs through electricity rate increases, strict liability would continue to apply.

Although IOUs faced strict liability, the precedent established by *Barham* ensured that their liability net of revenue increases from raised electricity rates would be low. The precedent that IOUs could recover liability costs through increased electricity rates was not tested until several damaging fires ignited by power lines operated by San Diego Gas and Electric in 2007. The 2007 fires were the first time since the *Barham* decision that the liability costs associated with power line-ignited fires exceeded an IOU's liability insurance coverage (Hafez 2020). As a result, San Diego Gas and Electric's application to recover uninsured liability costs through electricity rate increases was a novel test of the strict liability standard. Ultimately, CPUC rejected San Diego Gas and Electric's application to recover liability costs through electricity rates in December 2017, citing San Diego Gas and Electric's lack of precaution in preventing the 2007 fires as the deciding factor.[7] Because IOUs could no longer expect to automatically recover costs through electricity rate

5. The Court's decision argues that IOUs' ability to raise electricity rates is akin to a government's ability to levy taxes. IOUs are currently challenging this logic in court by pointing out that their ability to raise electricity rates is subject to approval by the CPUC.

6. Pacific Bell Telephone Co. v. Southern California Edison Co., 208 Cal. App. 4th 1400, 1403 (2012).

7. Application of San Diego Gas & Electric Company (U 902 E) for Authorization to Recover Costs Related to the 2007 Southern California Wildfires Recorded in the wildfire Expense Memorandum Account, filed Sept. 25, 2015. Decided Dec. 26, 2017.

increases following the 2017 CPUC decision, their liability for fire damages increased dramatically. CPUC's decision states that "If the preponderance of the evidence shows that the utility acted prudently, the Commission will allow the utility to recover costs from the ratepayers." While CPUC declined to define a precise negligence threshold in its decision, the decision dramatically increased each IOU's expected share of responsibility for liability.

The "prudent manager" standard remained in effect until SB 901 added section 451.1 to the Public Utilities Commission Code which took effect for all fires ignited after January 1, 2019. Section 451.1 replaced the "prudent manager" standard with twelve non-exclusive criteria that CPUC uses to determine whether an IOU can recover costs associated with fire liabilities through electricity rates. The criteria take into account the IOU's design, maintenance, and operation of assets in addition to the severity and unpredictability of the weather event which caused the ignition. While, section 451.1 clarified the standard used to judge each utility's negligence it still significantly increased the share of costs associated with fire damages utilities expected to bear relative to the pre-2017 regulatory environment. If the reader is interested in learning more about the history of liability law and IOUs in California, Hafez (2020) provides a complete and succinct description. The next section describes utilities' allocation of ignition prevention effort and demonstrates how increasing the share of damages born by IOUs changes this allocation.

1.3 The ignition prevention decision environment

IOUs face a complex decision making environment as they determine how and where to invest in strategies that lower the risk of fire ignited by their electrical infrastructure.[8] Utilities' ignition-prevention decisions have significant economic consequences; despite accounting for 1-5% of total fire ignitions in Southern California, utility-operated equipment accounts for 20-30% of total area burned by wildfires (Syphard and Keeley 2015). Ignitions by power lines typically occur between July and December and their two leading causes are wind-blown vegetation and equipment failure. Much of the transmission and distribution infrastructure operated by IOUs in California is outdated (in 2017 Pacific Gas and Electric estimated that the average age of its transmission towers was 68 years old). As climate change has increased vegetative aridity and the severity of weather events

8. This section draws from Wildfire Mitigation Plans submitted by Southern California Edison, Pacific Gas and Electric, and San Diego Gas and Electric to CPUC in 2019, 2020, and 2021.

in IOU service territories, the risk of fire ignition has also risen. In determining which areas to prioritize for ignition mitigation activities, utilities weigh the benefits of providing electricity to their residential, industrial, and commercial customers with the cost of each activity and the ignition risk associated with each section of their distribution and transmission infrastructure.

To determine the ignition risk of a section of power line, utilities consider historical and forecasted weather conditions, infrastructure age, vegetative growth, presence of outdated equipment with known ignition risk, and the value of electricity demanded by customers on that section. After determining the baseline risk of a power line segment, a team at each utility then chooses an ignition mitigation activity which reduces the risk at least cost. Utilities perform a range of ignition prevention activities including vegetation management, installation of weather stations along power lines, burying power lines underground, upgrading equipment, inspecting power lines, and turning off the power to targeted sections of the grid when weather conditions elevate the probability of ignition. Use of ignition prevention activities differs across utilities and over time as conditions change and utilities learn more about the effectiveness of each action. For example, Pacific Gas and Electric primarily deployed shutoff events and infrastructure upgrades in 2019 to reduce the probability of ignition, while Southern California Edison focused on installing covered conductors that reduce the probability of ignition on high risk assets. Recently, each IOU has increased efforts to bury sections of high-risk assets underground.

Precautionary actions available to utilities differ widely in their ability to prevent ignitions, their cost, and which individuals bear that cost. Power shutoffs, when targeted well, guarantee that an ignition cannot occur because electricity is not running through the line when an incident occurs. However, power shutoffs are also socially costly, sometimes leaving affected communities without power for extended periods of time. In contrast, the effectiveness of other types of precaution such as vegetation management may be more difficult to measure and impose costs on either the utilities or (if the cost of precautionary measures is incorporated into retail electricity rates) all electricity consumers in California.

Historically, utilities in California have not relied on power shutoffs to reduce the likelihood of ignition because they disrupt the service of electricity to customers. CPUC defines Public Safety Power Shutoff events as actions taken by utilities to temporarily turn off power to specific areas in order to reduce the risk of fires caused by electric infrastructure. Of the three largest IOUs in

California, only San Diego Gas and Electric utilized shutoffs to prevent ignitions prior to 2017.[9] Because shutoff events require the utility to interrupt service to customers it is seen as a measure of last resort to mitigate fire ignitions. As a result, each IOU has invested in devices which further segment high-risk areas of their transmission and distribution networks, allowing more targeted blackouts that affect fewer customers.

CPUC approves the use of power shutoff events by IOUs, first granting approval to San Diego Gas and Electric in 2012, Pacific Gas and Electric in 2018, and Southern California Edison in 2018. Figure 2 plots the share of total customer hours impacted by shutoff events between 2013 and 2023 by year separately for each of the three largest California utilities. The most affected customer hours occurred during 2019 in Pacific Gas and Electric's and Southern California Edison's service territories. A similar pattern exists for the number of commercial customer hours and medically vulnerable customer hours affected by power shutoffs. Between 2021-2023 all three utilities used power shutoffs less frequently than in previous years, potentially reflecting the transition to longer-term precautionary actions such as burying power lines underground. This study focuses on firms' short-run use of precaution between 2018 and 2020, leaving studies of long-run precautionary behavior for future work.

Utilities consider climatic conditions, the condition of electrical infrastructure, and the value of lost electricity load in potentially impacted areas to determine when and where to declare power shutoffs. Pacific Gas and Electric reports the criteria it uses to declare shutoff events on page 982 of its 2021 Wildfire Mitigation Plan. The minimum criteria for deciding a shutoff in a high fire threat area are sustained wind speeds greater than 20 miles per hour, dead fuel moisture below 9%, relative humidity below 30%, and a fire potential index greater than 0.2.[10] Despite these criteria, utilities have discretion in declaring power shutoffs: Abatzoglou, Smith, Swain, Ptak, and Kolden (2020) provide evidence that shutoff events are used more frequently by Pacific Gas and Electric than would be implied by their minimum climate criteria.[11]

Since 2019, several policy changes have altered firm's decision making process surrounding

9. San Diego Gas and Electric sought and received approval from CPUC to initiate power shutoffs in its service territory starting in 2013.

10. The fire potential index measures the likelihood of an ignition causing a catastrophic wildfire using wind speeds, temperature, humidity, dead and live fuel moisture, and vegetative cover types.

11. Abatzoglou, Smith, Swain, Ptak, and Kolden (2020) note that this could be due to differences in climate modelling between their study and Pacific Gas and Electric's internal methods.

shutoff events. In 2019, the state legislature created the California Wildfire Fund created which requires IOUs and ratepayers to each contribute $10.5 billion between 2020 and 2030 (2035 for ratepayers) to a fund that can be used to cover liabilities from power line-ignited fires. The fund allows utilities to self-insure against expected liabilities, and is projected to total $21 billion by 2035. To access funds, CPUC must determine that a utility acted "prudently" to mitigate ignition risk along its energy infrastructure. In this way, the fund acts as a self insurance mechanism with access determined according to a negligence standard determined by CPUC. Starting in 2023, CPUC also initiated a program to fine firms based on their adherence to regulatory requirements for public safety power shutoffs. Depending on the how broadly CPUC interprets adherence to the shutoff requirements, this citation program could decrease future use of shutoffs. Since this paper focuses on firms' short-run precautionary investments between 2018 and 2020, these programs are left for future research to examine. Although the Wildfire Fund was created in 2019, utilities did not submit a payment to the fund until July 2020 and no claims were processed from the fund until 2021.

According to Shavell 1986, firms should make increasingly costly precautionary investments as they face greater liability from a potential accident until their expected liability approaches their asset value. Thus, in the context of power line-ignited fires firms should undertake costlier power shutoffs when they face higher levels of liability and should be equally likely to declare a less costly shutoff across different levels of liability. Because utilities must visually inspect each distribution circuit that is shut down during a shutoff event, the cost of each additional public safety power shutoff increases significantly because it increases demand for scarce inspection resources. For example, consider two days with extreme fire risk at circuit A. On day 1, the utility has no ongoing public safety power shutoff events along other parts of its electrical grid in California, while on day 2 there are 1,000 miles of power lines already powered down due to public safety power shutoff events along other parts of its grid. Since demand for inspection inputs is low on day 1, the utility can cost effectively and quickly verify that circuit A is clear of debris and can be safely re-powered. Conversely, on day 2 demand for inspection inputs is high along the rest of the utility's grid, increasing the cost of an additional shutoff both because the additional shutoff will require increased inspection costs (through overtime pay for workers and increased utilization of capital such as helicopters and drones) and by increasing the expected duration of the shutoff. In 2023, costs associated with line patrols and line inspections were the largest line item associated with shutoff events in Southern California Edison's 2023 general rate case proceeding, accounting for 35% of total shutoff costs. Southern California Edison's rate case testimony explicitly underscores to significant costs associated with line inspections preceding circuit re-powering: "...the primary driver of line patrolling activities each year is the number of PSPS activation events" (SCE GRC 2023, p.22).

The next section develops a conceptual framework of liability in the context of the electric utility industry and presents several testable hypotheses.

2 Conceptual Framework

The conceptual framework demonstrates two points: (1) Increasing the level of potential liabilities could lead firms to use more or fewer power shutoffs. (2) Utilities use more shutoffs when ignitions are likely.

The framework in this paper is adapted from Lim and Yurukoglu (2018) who show that a regulator's inability to commit to a predictable path of capital returns leads utilities to systematically underinvest in capital. Here, I consider a simplified version of the model with no strategic interaction between the regulator and the utility. In this model, the utility takes the regulator's choice of capital return as given rather than as an output from a negotiation process.

For simplicity, I model a single utility's decision to make defensive capital investments and supply electricity to one distribution circuit. If the utility supplies electricity, it receives future net revenue and faces expected liability damages from a potential ignition along its power lines. However, if the utility declares a power shutoff it receives no revenue and faces no expected damages. The utility self protects against expected damages by making defensive capital investments that reduce the probability of ignition.[12] In making its decisions, the firm compares the marginal reduction in damages from self protection to total expected damages. Whenever expected damages exceed the marginal benefit of self protection, the firm shuts off the power.

I make several important assumptions in this model. First, because the model only considers one distribution circuit, the firm will never make additional defensive capital investments if it

12. I define self protection in the same way as Ehrlich and Becker (1972), where defensive investments reduce the probability of ignition rather than total damages.

shuts off the power. In practice, defensive investments may complement power shutoffs because utilities could self protect against damages on days when the ignition risk is low. Second, in a departure from reality, I do not allow for strategic interaction between the firm and the regulator. The results from Lim and Yurukoglu (2018) suggest that allowing for such interaction would cause firms to increase shutoff use more and invest in defensive capital less. Third, I do not model the firm's non-defensive capital investment decisions. Finally, the model assumes that consumers value their homes at the structure replacement cost. This simplifying assumption does not affect the framework's predictions, but it would increase the benefit of shutoffs for households in the calculation of how liability regulation affects social welfare in section 6.

2.1 Firm's Problem

The regulator sets a per unit output price p that allows the utility to recoup a reasonable return on defensive capital (γk) and per-unit liability costs (ν).

$$p = \gamma k + \nu \tag{1}$$

Where k represents the stock of firm defensive investment which it uses to self insure against damages from a potential fire ignition and γ is the exogenous rate of return on defensive investment that is set by the regulator. The firm inelastically supplies Q units of electricity to consumers who purchase a quantity Q of electricity up to a "choke" price ($\bar{p}$) above which they are no longer willing to pay.

$$D(p) = \begin{cases} Q & \text{if } p \leq \bar{p} \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

The utility earns revenue by supplying electricity to retail consumers and reduces expected liability costs by renting defensive capital that reduces damages from a potential ignition from households at the prevailing interest rate (r). The utility can also prevent ignitions by supplying no electricity to consumers (declaring a power shutoff).

$$\max\{\pi_1, \pi_0\}$$

Where

$$\pi_1(k) = \max_{k'}\{-r(k' - (1-\delta)k) + \beta(\phi pQ - Z)\}$$

$$\pi_0(k) = \max_{k'}\{-r(k' - (1-\delta)k) + \beta(pQ - \theta(k')(\bar{d} + \eta))\}$$

Where the utility earns π_1 in profits if it shuts off the power and π_0 in profits if it supplies power, δ is the capital depreciation rate, $\bar{d}$ is the dollar amount of liability damages if an ignition occurs, η is the dollar value of liability associated with fatalities related to a power line-ignited fire, and Z is the operational cost incurred by the firm to administer a power shutoff. In the empirical analysis later in this paper, $\bar{d}$ is the total replacement cost of structures threatened by a power line ignition. The utility can self protect against liability costs by investing in defensive capital (k') which reduces the probability of ignition ($\theta(k')$) or by declaring a power shutoff which reduces the probability of ignition to zero. When the utility shuts off the power it recoups a fraction $\phi \in [0, 1]$ of its revenues by exerting market power in wholesale electricity markets. β is the per-period discount factor. Substituting the price of electricity from equation 1, allows us to rewrite the utility's profit functions.

$$\pi_1 = \max_{k'}\{-r(k' - (1-\delta)k) + \beta(\phi\gamma k - Z)\}$$

$$\pi_0 = \max_{k'}\{-r(k' - (1-\delta)k) + \beta(\gamma k + \theta(k')(\nu - \bar{d} - \eta))\}$$

If the firm supplies electricity (π_0) it pays defensive capital rental costs today and receives future net revenues (pQ) while facing expected liability costs from a potential ignition ($\theta(k')(d \bar{+} \eta)$). Whenever the firm chooses to shutoff the power (π_1), it pays capital rental costs today and receives only a fraction of its revenue in the future, but since an ignition cannot occur it also faces no expected damages.

When the utility shuts off the power it creates lost producer and consumer surplus. Intuitively, the utility incurs a private cost from shutoffs through lost producer surplus and operational costs and benefits from shutoffs because it faces no expected liability cost. So the utility's privately optimal choice of shutoffs depends on the relative magnitude of producer surplus and expected liability costs. Importantly, the utility does not internalize the loss in consumer surplus when it turns off the power, causing the utility's privately optimal choice of shutoffs to exceed the socially optimal level.

The firm's optimal capital investment strategy when it declares a shutoff weighs the cost of capital (r) against the fraction of revenue recovered during the shutoff ($\phi\beta\gamma$):

$$r = \beta\phi\gamma \tag{3}$$

When the firm does not declare a shutoff, its optimal capital investment strategy equates the marginal cost of capital and its marginal rate of return net of the marginal reduction in expected liability:

$$r = \beta\gamma + \theta'(k')(\nu - \bar{d} - \eta) \tag{4}$$

Where $\theta'(k')$ is the marginal reduction in the probability of ignition following increased capital investments by the firm. The firm then chooses whether to declare a shutoff by comparing its optimized profit when it declares a shutoff (π_1^*) to its profit when it supplies electricity (π_0^*). Comparing the firm's shutoff and no-shutoff profit functions yields the following decision rule:

$$\theta(k'^*)(\bar{d} + \eta - \nu) > (1 - \phi)\gamma k'^* + Z \tag{5}$$

The firm declares a shutoff whenever its expected cost of an ignition, net of liability payments passed through to ratepayers exceeds its total cost of a shutoff (foregone revenue plus operational costs).

This paper empirically studies how firms' use of shutoffs responds to exogenous daily variation in expected structural ($\bar{d}$) and non-structural (η) liabilities. In particular, I observe whether firms declare shutoffs of varying operational cost (Z) as potential liabilities change across days. The conceptual framework yields three testable predictions regarding the relationship between liability and precaution: (1) when operational shutoff costs are sufficiently low and liability costs are not fully passed to ratepayers, firms' use of shutoffs should not vary across different levels of liability. In other words, firms should be equally likely to declare a low cost shutoff across different levels of liability. (2) When operational costs are large, firms should be more likely to use shutoffs at higher levels of liability. (3) When operational costs are large and a firm is judgment proof, then it should declare more costly shutoffs as liability increases until the liability if faces approaches its total asset value. In equation 5 the judgment proof problem is akin bounding the left hand side from above; e.g. there is a maximum level of expected damages that the firm can afford without going bankrupt.

The next section of the paper describes the empirical methodology and data used to test the predictions from the conceptual framework.

3 Empirical Framework

According to the theory developed in section 2, firms should declare costlier power shutoffs as the liability cost they bear increases if the firm is not judgment proof. One way to test this hypothesis would be to estimate a linear model that relates the probability of a shutoff at circuit i on day t (y_{it}) to the total replacement cost of structures near circuit i ($Value_i$) interacted with an indicator equal to one when the operational cost of the shutoff exceeds the median level observed throughout the sample period ($Cost_{it}$).

$$y_{it} = \nu_1 Value_i \times Cost_{it} + \nu_2 Value_i + \nu_3 Cost_{it} + \varepsilon_{it} \tag{6}$$

Because I do not directly observe operational costs related to shutoff events at each circuit i on day t, the empirical strategy relies on variation in an important driver of operational costs: the miles of power lines owned by the operator of circuit i that are already powered down as part of ongoing shutoff events on day t. Before a firm restores electricity service to a circuit that has been shutdown, workers are required to visually inspect the power lines to verify that there are no hazards which would cause an ignition upon re-energization. When there are many power line miles already powered down, firms' demand for scarce inspection resources increases, leading to greater utilization of more expensive inputs like drones and helicopters to complete inspections. This increased demand for inspection resources dramatically increases the overall operational cost of a shutoff event: In 2023, costs associated with line patrols and line inspections were the largest line item associated with shutoff events in Southern California Edison's 2023 general rate case proceeding, accounting for 35% of total shutoff costs. Southern California Edison's rate case testimony explicitly underscores to significant costs associated with line inspections preceding circuit re-powering: "...the primary driver of line patrolling activities each year is the number of PSPS activation events" (SCE General Rate Case 2023, p.22). Therefore, I replace $Cost_{it}$ with a binary indicator equal to one if the powerline miles already de-energized prior to the shutoff decision at circuit i on day t is above the sample-wide average observed at each firm.

Under the conditional independence assumption, $\nu_1 + \nu_2$ identifies the effect of liability on firms' use of shutoffs with above-median operational costs. However, the conditional independence assumption is unlikely to hold in this example because unobserved determinants of shutoffs such as the moisture content of vegetation, regional weather conditions, and the presence of critical energy infrastructure are likely correlated with structure replacement costs.

To isolate the causal effect of structure replacement cost on shutoffs, I rely on a widely-used model of fire spread called "Elmfire" (Lautenberger 2013) to predict daily expected damages from potential fire ignitions along power lines in California. Since factors that drive daily variation in expected damages from power line-ignited fires, such as the interaction between wind patterns and landscape characteristics such as slope and vegetation type, are more plausibly exogenous, the conditional independence assumption is likely to be satisfied in this setting.

Elmfire uses a mathematical technique called the Eulerian level set method to model the interplay between burned and unburned pixels on a regular grid and is widely used by organizations that work with electric utility companies (such as Pyregence and FirstStreet) to study both historical fires and potential ignitions. Elmfire adopts the same set of standard assumptions about fire spread, such as the Rothermel surface spread model, as in other models such as FARSITE (Finney 1998), with additional parameterization that reduces computation time. The Elmfire model is open source, available at https://elmfire.io, and relies on several inputs that are listed in Table X. Static landscape characteristics including vegetation type and canopy height were collected from Landfire 2022 which is created by shared wildfire management programs at the US Forest Service and the US Department of the Interior. Landscape slope and elevation were collected from the US Geological Survey 3DEP program. Hourly wind conditions at 10 meters above the Earth's surface are collected from the National Oceanic and Atmospheric Administration's Real Time Mesoscale Analysis (RTMA) data product. Gridded data on population per acre for the state of California, based on the 2020 census was collected from Depsky, Cushing, and Morello-Frosch (2022). Finally, gridded data reporting structure replacement costs per acre across California was created from Zillow's ZTRAX database.

Ideally, a researcher would model daily fire risk by simulating fires ignited at randomly selected points along power lines at each hour of the day. Such an analysis was not feasible due to the significant computation time required to simulate fires along the extensive networks of distribution lines across California for every day between 2018 and 2020.[13] Instead, this analysis develops a surrogate model of fire risk which simulates fire ignitions at randomly selected points within 300 clusters of distribution circuits across California for a representative sub-sample of days.[14] Distribution circuits were grouped into 300 mutually exclusive clusters of power lines (100 clusters per firm) using the non-parametric k-means clustering algorithm and 16 representative days were randomly selected for each cluster according to local wind conditions and seasonality. Specifically, I categorized each cluster-day according to one of four prevailing wind directions (NE,SE,SW,NW), whether daily average wind speeds were above/below the 75th percentile observed at that cluster, and season (April-November or December-March). After characterizing daily fire risk for this sub-sample, I assign fire risk to the rest of cluster-days according to the local wind conditions and seasonality. For example, the same cluster of circuits observed on consecutive days in April with wind blowing from the northwest and wind speeds below the sample-wide 75th percentile observed at that cluster would be assigned the same fire risk and expected liability. Thus, changes in expected liability risk across days are driven by changes in local wind direction, wind speed, and seasonality

13. Running in parallel across twenty compute cores, Elmfire completes one 24-hour simulation in approximately five minutes for a typical cluster of circuits. Even when parallelizing each daily run across up to 100 compute nodes computation times approach 1 year due to resource constraints.

14. Some of the computing for this project was performed at the OU Supercomputing Center for Education Research (OSCER) at the University of Oklahoma (OU).

at each circuit.

To ensure that the model accounts for intra-day changes in fire risk and differences in ignition probabilities across power lines within each cluster, I simulated 20 separate fire ignitions at 8am, 2pm, and 8pm pacific time (for a total of 60 simulations per day). I chose this timing of fire ignitions to match the distribution of power line ignited fires reported by utilities between 2014 and 2023 shown in Figure A1. For each of the 60 daily simulations, Elmfire integrates across the burned area to calculate the total affected property values. To calculate daily expected damages from potential fire ignitions I then calculated the average affected property value for each cluster and day.

Due to the limited availability of gridded data reporting hourly dead fuel moisture for southern California and increased computation time of running Elmfire with variable fuel moisture conditions, I held dead fuel moisture conditions constant during all of the wildfire simulations. Thus, daily changes in expected damages are driven primarily by the interaction of wind conditions with static landscape conditions.

Figure 3 demonstrates how variation in wind conditions across days leads to differential exposure to liability risk from a potential fire ignition using part of a distribution circuit operated by PG&E in northern California on May 5 and 6, 2019. The black lines represent distribution power lines and the blue area represents area that was burned during the 60 daily fire simulations while the white region remained unburned. Variation in the blue shading depicts both variation in burn probabilities (the number of times per day each pixel burned divided by 60) across pixels and variation in structure replacement costs across pixels. On May 5, 2019 the prevailing winds were from the southeast and were below the 75th percentile of observed wind speeds at this circuit, while on May 6 prevailing winds were from the northwest and observed wind speeds were above the 75th percentile. This variation in wind speed and direction affects both pixel burn probabilities and structures exposed to the potential fire, as demonstrated by the greater fire spread to the northwest of the power lines on May 5 and significantly increased risk to the southeast of the power lines on May 6. Since the area to the southeast of the power lines has greater property values, the expected liability risk borne by PG&E increases by around 14% across days from $89 million to $101 million.

Equation 7 formalizes this example into an empirical research design that links firms' use of power shutoffs to their daily exposure to liability risk.

$$(7)\quad y_{it} = \beta_1 Liability_{it} \times AffectedMiles_{it} + \beta_2 Liability_{it} + \beta_3 AffectedMiles_{it} + \beta_4 X_{it} + \nu_i + \delta_t + \varepsilon_{it}$$

Where y_{it} is a binary variable indicating whether there was an active shutoff event at circuit-cluster i on day t, $ExpectedLiability_{it}$ is the logged expected value of structures affected by potential ignitions at cluster-group i from the Elmfire simulations, and X_{it} is a vector of time-varying circuit-specific controls including daily wind speed, prevailing wind direction, maximum temperature, precipitation, relative humidity, and vapor-pressure deficit which all contribute directly to fire risk. Importantly, X_{it} also includes the expected total population affected by potential fire ignitions which accounts for changes in the probability of a shutoff that are driven by population exposure rather than liability for damaged structures. Since the effect of affected population is relevant in determining potential liability for injury or mortality related to potential fire ignitions, this variable helps to further identify the effect of liability on shutoff use. To account for static characteristics of each cluster-group, such as underlying vegetation type or slope, the model includes cluster-group fixed effects (ν_i). Finally, week-of-the-year and firm-year fixed effects (δ_t) capture variation in fire weather conditions over time and changes to firms' wildfire mitigation strategies across years. The coefficient of interest, β_1, measures the percentage point change in shutoff use in response to a 1 percent increase in expected daily liability.

The coefficient of interest, β_1 may not capture the causal effect of liability on power shutoff declaration if daily variation in wind direction is correlated with a community's underlying fire severity. I account for this possibility by controlling for a daily measure of fire risk at each circuit called the burning index and two separate daily measures of vegetation moisture at each circuit. I provide more information on these controls and their sources in section 4.

Since I de-mean the structure replacement cost in equation 7, β_3 is the change in shutoff likelihood when a zip code with average structure replacement cost is downwind. The coefficient of interest β_1 measures the average percentage point change in the likelihood of a power shutoff with respect to a one percent increase in downwind structure replacement cost. Furthermore note that while the coefficient β_2 captures the effect of non-threatened property values, it cannot be estimated because the replacement cost is collinear with the pair fixed effects. Under the conditional independence assumption, β_1 and β_3 identify the causal effect of downwind structure replacement cost on the probability of a shutoff.

4 Data

4.1 Outcomes

Power Shutoff Events I obtain the date, duration, location, and number of impacted customers from power shutoff post-event reports for the period 2013-2020 from the California Public Utilities Commission.[15] Since Pacific Gas and Electric, Southern California Edison, and San Diego Gas and Electric serve nearly 80% of electricity consumers in California and account for the largest share of power shutoffs historically, I restrict the sample to events initiated by one of these utilities. Furthermore, I exclude publicly owned utilities from this analysis because they have not been granted the authority to conduct power shutoff events by the regulator. As shown in Table 1, there were 46 concurrent power shutoffs on the most active day of power shutoffs in my sample. However, shutoff events are very infrequent at the daily level, occurring on average 3.1% percent of total pair-days in the sample. The last row of Table 1 shows that there are 546 zip codes in California that ever experience a shutoff between 2018 and 2020.

Energy Infrastructure Information on the geographic location of distribution and transmission lines operated by Pacific Gas and Electric, Southern California Edison, and San Diego Gas and Electric is collected from publicly available Geographic Information System (GIS) files submitted to the California Office of Infrastructure Safety in 2020. The GIS data shows the location of each transmission and distribution line within a circuit and exclude critical energy infrastructure. Since the California Public Utility Commission reports shutoff events at the circuit level, I aggregate the line level data to the circuit level before string matching events to circuits by circuit name. On average across the three utilities, I match 97 percent of events to circuits using string matching.

15. Utilities are required to submit under Ordering Paragraph 1 of California Public Utilities Commission (CPUC) Decision (D.) 19-05-042.

4.2 Treatment and Control Variables

Replacement Cost of Structures Since electric utilities are liable for the cost of replacing structures damaged by power line-ignited fires, I use parcel-level structure replacement costs to measure potential damages rather than the market value of each property. I obtain parcel level replacement costs of each property in California in the most recent year that it is assessed prior to 2018 from the Zillow Transaction and Assessment Database (ZTRAX) which contains parcel-level assessed values and transaction information for most counties in the U.S. Zillow computes the replacement cost by taking the difference between the market value of the property and the market value of the land in the year of assessment. I adjust replacement costs to 2021 dollars using the consumer price index.[16]

Population Following a power line-ignited fire, firms could face liability for direct harms on affected populations from the fire or reputational costs that scale with the number of affected individuals. To separately estimate the effect of the expected population affected by a potential fire from the effect of property-related damages, I collected gridded population counts per acre from Depsky, Cushing, and Morello-Frosch 2022 which are used as inputs to the Elmfire model of fire spread. Elmfire integrates across the simulated burned area to calculate the population affected by a potential fire ignition.

Climate conditions To measure daily climate conditions at each circuit, I collected wind speed, wind direction, maximum temperature, maximum relative humidity, cumulative precipitation, average vapor pressure deficit, reference grass and alfalfa evapotranspiration, and the burning index from the Climatology Lab at the University of California, Merced. The gridMET data product uses climatological interpolation to construct daily, surface level climate conditions on a 4km grid for the continental US. The burning index is a relative scale, with higher numbers representing the amount of effort required to contain a fire that has ignited and evapotranspiration measures the removal of water from local vegetation due to evaporation and transpiration. Both the burning index and the evapotranspiration measures are utilized by fire management agencies across the US.

16. Federal Reserve Economic Datahttps://fred.stlouisfed.org/series/CPALTT01USA659N. I added parcel level replacement costs across all parcels located within the same square acre grid cell using parcel centroids to get a gridded map of total replacement cost per acre. This raster was then input into the Elmfire model of wildfire spread which integrates across the simulated burned area to calculate the value of structures affected by a potential fire ignition.

Summary statistics Public safety power shutoffs occur rarely at the daily level between 2018 and 2020 (on 0.6% of sample days), affecting an average of 39 customers per event. On average, there were about 2 ongoing shutoffs with 87 miles of power lines deenergized across the sample. The expected liability faced by firms varies significantly across days and circuits with a standard deviation of $90 million and a maximum exposure of $1 billion for a single circuit-day. On average, 1 million individuals would be exposed to a potential power line ignition and this number varies significantly across the sample, with as many as 18 million people affected on a single circuit-day. Simulated fires range from 0 (no ignition) to 29,000 acres, reflecting the significant variation in potentially affected area depending on climate and vegetation conditions, elevation, and burnable land near power lines. Daily wind direction is predominantly from the West across all circuits and average daily wind speeds vary significantly across the sample from 1 to 43 mph. The average burning index across the sample is 35, which corresponds to medium fire danger according to the American Meteorological Society. The final sample consists of 300 distribution circuit clusters (100 per firm) observed every day between 2018 and 2020 (328,800 unique observations).

5 Results

Table 2 reports the baseline estimates from equation 7. Row 1 reports the average percentage point change in the probability power shutoff declaration that results from a 10 percent increase in downwind liability relative to when there are below median line miles affected by pre-existing shutoffs. Rows 2 and 3 report the difference in shutoff probability when there are above versus below median line miles already affected by shutoffs and the response of shutoffs to liability when there are below median line miles affected by ongoing shutoffs respectively. The coefficient of interest is the sum of the estimates from rows (1) and (3) and is very close to the reported coefficients in row (1) since the estimates in row (3) are economically and statistically small across all specifications. Rows (4) and (5) report the percentage point effect of a 10% increase in population affected by a potential ignition and potential fire size respectively. Column 1 reports the unconditional effect of expected liability on shutoff declaration, column 2 adds controls for climate conditions for each circuit-day which were described above, column 3 adds circuit fixed effects, and column 4 further adds calendar day fixed effects.

The coefficient of interest suggests that, on average, firms are 0.03 percentage points more likely to use a power shutoff with larger operational costs in response to a 10% increase in expected liability (mean of the dependent variable is 0.006). Across specifications, the coefficient of interest is significant at the 1% confidence level. The estimate in row 3, column 4 suggests that there is no change in the use of shutoffs with lower operational costs following a 10% increase in expected liability. Taken together, these results confirm predictions 1 and 2 from the conceptual framework: (1) firms should be equally likely to declare lower cost shutoffs when expected liability is high versus when it is low, (2) on average and conditional the firm avoiding bankruptcy, firms should increase their use of more costly shutoffs as liability increases. Intuitively, the estimate in row 3 implies that at the mean circuit firms are 0.22 percentage points likelier to use a shutoff on days where there already greater than the median line miles de-energized, reflecting the increased probability of a shutoff at any circuit on days when a firm has multiple other shutoff events ongoing.

The estimates in rows 4 and 5 provide weak evidence that shutoff use is positively related to the expected number of people affected by a potential ignition and negatively related to the size of a potential fire (both estimates are statistically significant at the 10% confidence level). On average, moving from below to above the fourth quartile of wind speeds implies a 3 percentage point increase in shutoff declaration, underscoring the importance of wind conditions in firms' shutoff decision-making process. Characteristics indicative of vegetative aridity such as relative humidity and vapor pressure deficit are also highly predictive of power shutoffs. Finally, the burning index is positively correlated with power shutoff use at the mean circuit, highlighting its wide use by utilities in forecasting climate conditions.

Although prior work suggests that the relationship between liability and precaution should be nonlinear, the estimates in Table 2 assume a linear relationship. I relax this linearity assumption by binning expected liability by quartile and re-estimating equation 7. Figure 4 reports the effect of expected liability binned by firm-specific quartile. The estimates in Figure 4 suggest that, on average, firms use costlier shutoffs more as expected liability increases beyond the the median level for each firm ($50 million for PG&E, $30 million for SCE and SDG&E).

Shavell (1986) posits that as liability approached the firm's total asset value, precautions to prevent an accident will not further increase. I can directly test this prediction by redefining the treatment variable of interest in equation 7 as the ratio of potential liabilities to each firm's total asset value for each destination zip code in the sample.[17] As above, I bin the asset share by decile to allow for non-linearity in the relationship between liability and firms' precautions.

The estimates in Figure 4 are consistent with this prediction. On average, firms take greater precautions until their total liability from a potential ignition exceeds \$10 billion and then begin to take less precautions. To provide direct evidence of how firms' shutoff use responds as expected liabilities comprise an increasing share of their total asset value, I divide expected downwind liabilities by each firms' 2022 asset value and bin the resulting shares by decile. Figure 5 reports the estimates and confidence intervals from a modified version of equation 7 which replaces expected liability with deciles of firm asset value shares. While expected liabilities at each individual circuit make up between 0 and 1% of firms' 2022 asset value throughout the sample, firms face substantial expected liabilities across all circuits that they operate with total expected liability between 6 and 8% of their 2022 asset value, on average. As predicted, by Shavell 1986 on average, firms undertake costlier shutoffs as the share of expected liability over asset value increases. Once the share of expected liability over asset value exceeds 0.08% there is no evidence that firms continue to use costlier shutoffs with increasing frequency, providing support for the hypothesis that firms' precautionary effort may plateau when expected liabilities make up an increasingly large share of firm asset value.

Each of the three firms analyzed in the main empirical analysis has idiosyncratic characteristics, such as underlying level of bankruptcy risk and ignition risk across their service territories, which may affect their response to expected liability. For example, PG&E declared bankruptcy in 2019 and operates the largest service territory of the three firms while SDG&E manages the smallest service territory and has invested in precautionary measures for longer than the other firms. To account for heterogeneity across firms, I re-estimate equation 7 with expected liability as a share of 2022 firm asset value binned by decile for each firm and interact the treatment with an indicator for each firm. These firm-specific results are reported in Appendix Figures C1, C2, and C3. The estimates and their associated 95% confidence intervals are reported by above or below median miles of line affected by ongoing shutoffs (red and blue lines respectively) and share of firm asset value. The results indicate that SD&GE is dramatically more likely to use a costly shutoff as expected

17. Specifically, I calculate the ratio of total zip code replacement costs to PG&E, SCE, and SDG&E's 2022 total asset values.

liability increases at the average circuit, with shutoffs increasing by 0.5 percentage points when expected liability is 0.12% of its total asset value relative to when expected liability comprises a negligible share of asset value. At the mean circuit operated by SCE, costly shutoff use increases as expected liability increases relative to asset value, although the increase is smaller and less precisely estimated than that for SDG&E. At the average circuit PG&E's use of costly shutoffs does not respond to increasing expected liability as a share of asset value.

Overall, these results indicate that short-run precautionary investments made by SDG&E (and to a lesser extent SCE) are, on average, much more responsive to expected liability than those made by PG&E. These results are intuitive for several reasons. First, of the three firms, SDG&E has the longest experience with modeling ignition risk and potential fire consequences along its electricity infrastructure, with a program dating back to 2008.[18] Given SDG&E's experience with fire modeling, it may more effectively model and respond to expected liabilities throughout its service territory. Second, PG&E serves a larger service territory with more extreme expected liabilities than the other two firms. While firms' average daily expected liability as a share of asset value across all their distribution circuits is around 8%, PG&E experiences larger extreme liabilities across its service territory with total daily expected liabilities as high as 12% of firm asset value (9% for SCE and SDG&E). This larger exposure to extreme expected liability means that PG&E has greater exposure to bankruptcy risk than the other firms, increasing the potential for the judgment proof problem.

5.1 Robustness

The empirical model in equation 7 uses daily changes in downwind structure costs to estimate the relationship between shutoffs and liability. However, evidence suggests that utilities monitor forecast wind conditions in addition to current conditions. As a result, utilities may base their shutoff decisions on their expectation of which regions will be downwind in the upcoming days. To account for this behavior, I calculate the average expected liability at each circuit cluster over the next two and five days and replace expected liability with this value in equation 7. Table **??** reports the estimates and standard errors associated with the 95% confidence level. The

18. See https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M520/K467/520467882.PDFCPUC (2023) for more details.

baseline estimates, two-day expected liability estimates, and five-day expected liability estimates are reported in columns 1, 2, and 3 respectively. The coefficient of interest is reported in row 3 and is positive, significant, and of a similar magnitude across all specifications.

Appendix B presents the results of two additional alternative specifications. Table B1 presents estimates from a poisson model of the relationship between expected liability and firms' declaration of costly shutoffs. The coefficient is of a similar magnitude as the baseline estimates reported in Table 2, although imprecisely estimated.

As a final robustness check, I replace the outcome in equation 7 with a continuous variable measuring the number of customer hours without power at each circuit cluster. Since there are many hours where no customers experience a power shutoff, I use the inverse hyperbolic sine transformation of customer hours without power rather than the log transformation. The estimated coefficient of interest in row 3 of Table B2 suggests that, at the average circuit, increasing liability by 10% leads to 0.35 additional customer hours without power. Estimates are stable and statistically significant at the 1% percent confidence level.

6 Discussion and Conclusion

This paper provides the first causal evidence of how firms' precautions responds to liability across the full distribution of potential liabilities that they face. I document a nonlinear relationship between potential liability and firm precautions in California's electric utility sector, showing that firms increase precautions until liabilities are extreme. While this is a novel result that helps inform existing models of firm precautions, it can also be used to determine how a negligence rule which reduces firms' exposure to expected liabilities affected social welfare. The welfare effects of reducing firms' exposure to liability are unclear in this setting because the type of precaution firms utilize in the short run, power shutoffs, provide both positive and negative welfare consequences to Californians and firms. Power shutoffs generate positive welfare effects because they reduce the likelihood of fire ignition by power lines, and their associated damages. However shutoffs also leave consumers without power, sometimes for extended periods of time and impose operational costs on firms. In the short run, the net change in social welfare depends on the relative magnitude of averted damages from power shutoffs and the combined value of consumers' lost electricity use during shutoffs and firms' operational cost of shutoffs. The long-run welfare consequences of lowering firm exposure to liability in this setting additionally depend on the relationship between power shutoffs and other types of precautions like burying power lines underground, the relative effectiveness of shutoffs versus other types of precautions, and the long-run effect of liability on other types of precautions such as electrical grid hardening. Since this paper is focused on firms' short-run precautionary response to liability, I leave the long-run welfare consequences of liability regulations for future work.

6.1 Short Run Welfare

Thus far, I have provided empirical evidence suggesting that precautions and liability are positively related when expected liabilities make up a small fraction of total firm asset value and unrelated when the ratio of expected liabilities to firm asset value is large. The welfare implications of this relationship are ambiguous for two key reasons. First, power shutoffs impose costs on households that lose power while also preventing structure destruction from power line ignited fires, ambiguously affecting household welfare. Second, shutoffs may increase or decrease firm welfare depending on whether firms' response to downwind liabilities increases or decreases their expected liability payments.

Using the conceptual framework from section 2, I derive the short-run welfare change resulting from an increase in liabilities from a potential ignition in Appendix D. The short run welfare change from changing firm liability from $\bar{d}$ to $\bar{d}'$ is shown below.

$$\begin{aligned} WF(\bar{d}') - WF(\bar{d}) =& \beta(\theta\eta - Z - \bar{p}Q)\Big[P(L \mid \bar{d}') - P(L \mid \bar{d})\Big] \\ & - \beta\theta(\bar{d}'(1 - P(L \mid \bar{d}')) - \bar{d}(1 - P(L \mid \bar{d}))) \end{aligned} \tag{8}$$

Where $\bar{p}$ is the consumers' maximum willingness to pay per kilowatt hour, Q is the amount of electricity consumed by households, Z is each firms' cost of executing a shutoff event, $\bar{d} < \bar{d}'$ are damages that firms are liable to pay, η represents non-building related expected liabilities (e.g. from potential fatalities), $P(L \mid \bar{d})$ is the probability of a power shutoff, and θ is the probability of ignition from power lines.

Five parameters characterize the relative short-run welfare change from a change in damages when shutoffs do versus do not depend on potential liabilities in equation 8: (1) the change in probability of shutoff event following an increase in the share of liability born by firms ($P(L = 1 \mid \bar{d}') - P(L = 1 \mid \bar{d})$), (2) the relative change in expected damages when firms do not declare a power shutoff ($\beta\theta[\bar{d}'(1 - P(L \mid \bar{d}')) - \bar{d}(1 - P(L \mid \bar{d}))]$), (3) consumers' maximum willingness to pay for electricity ($\bar{p}$), (4) firms' expected liabilities associated with potential fatalities from power line ignited-fires ($\theta\eta$), and (5) firms' operational cost from administering a power shutoff event.

There are several important caveats to the welfare change represented in equation 8. In the model, consumers value their home at its replacement cost and receive a payment from the utility equal to the home replacement cost if the structure burns down. As a result, households in this model are indifferent whether or not their home burns down. In practice, consumers may have a value of their home which exceeds the replacement cost, causing consumer surplus to potentially increase when firms use more shutoffs. Thus, the welfare change in equation 8 is likely larger (in absolute terms) than a more detailed model that incorporates intrinsic home values.

I also assume that the adjustment of defensive capital cannot occur in the short term (making term three in Appendix D, equation 2 equal to zero). Since the sample includes three post-policy years and the utilities have extensive networks of power lines, the extent of defensive capital investment is limited in this setting. However, future analyses of defensive capital's impact on the likelihood of ignition would be informative.

Finally, I assume that the firm is risk neutral and maximizes expected utility. There is evidence that utilities have been interested in purchasing private insurance for wildfire-related liabilities, making firm operators potentially risk averse. Appendix F derives the welfare change for a risk averse firm owner under an assumption that depreciation rate of capital is zero.

To compute the welfare change in equation 8 for each circuit cluster, I use the estimated relationship between liability and power shutoff use from this paper, estimates of the probability of power line fire ignitions at each circuit reported by each utility, data on total zip code energy demand, an estimate of consumers' valuation of lost electricity demand during a power outage, power shutoff duration in hours, estimates of each firms' average operational cost associated with a public safety power outage, and estimates of fatality-related damages based on a \$13 million value of a statistical life and a Pareto distribution of fire fatalities. Appendix E explains this process in detail.

Since there is a wide range of empirical estimates of the value of lost load, I bound the short run welfare effect using the smallest and largest estimates from the existing literature. The largest estimate of the value of lost load from Gorman (2022) is \$65 per kWh, while the smallest estimate for my sample period is the average retail price of electricity in California in 2018 (\$0.20 per kWh).

Since the current regulatory regime in California imposes strict liability for damages from power line ignited fires, I calculate the welfare impacts associated with decreasing, or limiting, firms' expected liability from the third to the first quartile observed at each circuit cluster (on average, limiting liability per cluster from \$74 to \$54 million). Thus, in Equation 8 $\bar{d}'$ corresponds to the first quartile of expected liability at each circuit cluster and $\bar{d}$ corresponds to the third quartile.

The average circuit-level welfare effects with the low and high consumer values of electricity use are reported in Figures E1 and E2 respectively. Each bar represents the number of circuit clusters in a specific welfare effect bin and circuits are shown in separate colors for PG&E, SCE, and SDG&E. With a low value of lost load (Figure E1) circuits operated by PG&E and SDG&E have small, positive welfare gains that are less than \$1 million. The welfare effects for SCE's circuits are much more dispersed, with some circuits experiencing a welfare loss as large as \$2 million and other circuits gaining as much as \$3 million. The wide dispersion in SCE's welfare effects appears to be driven by outliers with extreme ignition probabilities relative to most of SCE's circuits and those circuits operated by other firms.

Increasing the value of lost load (Figure E2) unambiguously increases the welfare effect of limiting liability at all circuits because firms use fewer shutoffs, on average, when their expected liability decreases (according to the estimates from Table 2). While average welfare effects vary across firms, they are concentrated between \$200,000 and \$5 million for most circuits. On aggregate, limiting expected liability at each circuit would increase welfare by between \$27 dollars (low value of lost load) and \$270 dollars (high value of lost load). In sum, even when the value of lost load is only \$0.2 per kWh, most circuits experience a net welfare benefit from reducing expected liability from the third to the first quartile observed at each circuit. In other words, the benefits from decreased shutoff use (fewer hours without power for consumers and lower operational costs associated with shutoffs) tend to outweigh the costs (expected liabilities from potential fire ignitions) at most circuits in the sample even when consumer's value of electricity use is quite low. One driver of this result is the low probability of ignition across all circuits: the median ignition probability across all circuits in the sample is 0.03%. Since the primary cost of decreased power shutoff use is the product of the ignition probability and (separately) expected structure replacement costs or expected fatalities, the welfare benefits tend to outweigh the costs at most circuits.

6.2 Conclusion

In this paper I use exogenous daily variation in wind direction to estimate the causal relationship between liability and short-run firm precaution across the full distribution of liabilities that firms face in California's electric utility sector. Theoretical models of firm behavior suggest that firms make increasingly costly precautionary investments as their expected liabilities from an accident increase. Prior empirical work estimates the relationship between liability and firm precaution at one point in the distribution of liabilities that it faces, ignoring important non-linearities in firm precaution. This paper advances the previous empirical literature by developing an empirical framework that can estimate the causal relationship between liability and firm precaution across the full distribution of liabilities it faces, capturing these non-linearities.

To evaluate the effectiveness of liability regulations, I study California's electric utility sector, a setting where firms face extreme liability from fires ignited by the power lines that they operate. I construct a daily panel of circuit clusters across California between 2018 and 2020 and use exogenous daily variation in exposure potential power line-ignited fires to estimate how firms use of power shutoffs to prevent fire ignitions changes as the value of structures downwind of their power lines varies.

This paper finds that at the mean circuit, firms increase precautions in response to the level of liability that they face. However, firms' precautionary response to liability is highly non-linear and varies widely across firms: On average, I find that SDG&E is much more responsive to expected liability than PG&E and SCE. SDG&E has more experience modelling fire risk along its power lines and relatively lower exposure to expected liabilities than PG&E and SCE, suggesting that sophistication in modelling areas affected by power line ignited fires and exposure to bankruptcy risk are relevant determinants of firms' short run precautionary investments.

The estimates from Figure C2 suggest that the most responsive firm, SDG&E, increases its use of power shutoffs by 0.4 percentage points, on average, when its expected liability increases by approximately \$60 million (from the first to eighth decile of SDG&E's observed expected liability in the sample). However, this value of expected damages is conditional on an ignition occurring. To obtain an estimate of SDG&E's unconditional change expected damages we multiplied \$60 million by the average probability of ignition reported by SDG&E across the circuits it operates (0.001) to arrive at an estimate of a 0.4 percentage point increase in shutoff likelihood in response to a \$60,000 increase in unconditional expected liability. Then, using an estimate of SDG&E's operational cost per customer hour affected by shutoff events in 2020 from its 2023 General Rate Case (\$28.95 per customer hour) I can approximate the dollar change in precautionary investment per dollar of expected liability. Specifically, I calculate the ninetieth percentile of customer hours affected by a shutoff event for SDG&E during 2020 (50,328) and multiply by the per customer hour cost of a shutoff event to obtain an approximation of the cost SDG&E might incur by declaring a costly shutoff. Taking the product of the estimated coefficient (0.4) and the estimated operational cost of an additional shutoff (\$1.5 million) yields an increase of \$580,000 in precautionary investment in response to a \$60,000 increase in expected liability, or about \$10 of short run precautionary investment per dollar of exposure to expected liability.

This findings of this paper have several implications for policymakers: First, the firms with more experience in modeling fire risk and lower expected liabilities relative to total asset value made more costly precautionary investments as liabilities increased at the average circuit. Even for those firms with smaller shares of liabilities to asset value, the estimates from this paper suggest that costly precautionary investments at the average circuit plateau once expected liabilities are 0.08-0.12 percent of the firms' asset value. In other words, on average, increasing firms' circuit-level expected liability beyond 0.12 percent of each firms' asset value may not induce the firm to make more costly short-run precautionary investments. When designing the standard of short-run precautionary care firms must meet in order to pass liability costs to consumers, policymakers could assign unique standards to different regions of firms' service territories depending on the relative size of expected liabilities to asset value.

Second, PGE, the firm with the most extreme exposure to expected liability and that underwent bankruptcy from 2019-2020, did not make more costly short-run precautionary investments at the mean circuit as its expected liability increased. This is informative for the post-2020 regulatory environment following the creation of the California Wildfire Fund, which requires IOUs and ratepayers to each contribute $10.5 billion between 2020 and 2030 (2035 for ratepayers) to a fund that can be used to cover liabilities from power line-ignited fires. The fund allows utilities to self-insure against expected liabilities, and is projected to total $21 billion by 2035. To the extent that this self-insurance helps to prevent firms from entering bankruptcy, the estimates from this paper suggest that firms may increase short run precautions. In order to access the funds, the California Public Utility Commission must determine that the utility took "prudent" action to prevent fire ignitions. In choosing this standard of care, this paper's estimates suggest that policymakers should carefully weigh incentives for precaution against the likelihood of bankruptcy. On average, designing standards that target only the circuits with the most extreme expected liability may miss opportunities for cost effective short-run precautionary investments in regions of the grid with similar ignition risk, but less extreme liability.

Finally, the strategy used to quantify liabilities along firms' power lines could be used by regulators to implement a tax on expected liabilities levied on firms. Such a tax would be feasible in this setting–fire simulation models such as Elmfire are already used at large scale to study ignition risk and regulators already ask firms to quantify how precautionary investments reduce this risk. Since the expected liability faced by a firm (inclusive of ignition risk) is low on an average day, firms' annual tax burden would be unlikely to trigger bankruptcy. Furthermore, the tax would provide a clear incentive for precautionary investments by directly linking firms' effort to reductions in financial burden as investments decrease ignition risk. Such a regulatory regime merits future analysis in this setting.

There are several areas where future research can extend this analysis to further inform our knowledge of liability regulations and how they impact firm precaution in the power line-ignited fire setting. First, future research should explore whether the circuits with the highest welfare loss from an increase in liability are located in areas with a large share of disadvantaged community members. For example, if expected damages are low and the value of lost load is high in disadvantaged communities, then this implies that increasing the share of liability on firms is regressive in this setting. Second, future studies should take a longer term view of the impact of liability regulation on utilities' ignition prevention behavior. Although reducing firms' exposure to expected liability has a positive welfare impact in the short term, it could be ambiguous in the long term if it encourages precautionary activities that both reduce the likelihood of ignition and while increasing the probability that a power shutoff occurs. As shown in Figure 2, firms decreased their use of public safety power shutoffs starting in 2021. This decrease could result if capital-intensive precautionary investments substitute for power shutoffs, but could also be due to policy changes such as CPUC's citation program for improper use of shutoffs or the California Wildfire Fund. Future work can address the extent to which one or both of these explanations explain the decrease in shutoff use after 2020. Finally, more work is needed to identify which ignition prevention strategies most effectively reduce the likelihood of a fire caused by power lines.[19] In particular, cost benefit analyses may need to be revised to account for the fact that capital investments both reduce the probability of ignitions *and* blackouts in the future.

19. Warner, Callaway, and Fowlie (2024) provides helpful information on long-term precautionary behavior by collecting data on other measures of ignition prevention, such as burying power lines.

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7 Tables

Table 1: Daily Circuit Panel Summary Statistics

	Mean (SD)	Min	Max	N
A. Power Shutoff Characteristics				
Number of Shutoffs	0.024	0	64	328,800
	(0.50)			
Shutoff Indicator (0/1)	0.006	0	1	328,800
	(0.07)			
Number of Affected Customers	38.678	0	207,300	328,800
	(1,233.09)			
Length of Shutoff (Hours)	1.038	0	3,018	328,800
	(26.95)			
Number of of Ongoing Shutoffs	1.606	0	502	328,800
	(17.08)			
Circuit-Miles Affected by Ongoing Shutoffs	87.350	0	30,420	328,800
	(1,033.74)			
B. Expected Fire Characteristics				
Liability (Millions of USD)	65.076	0	1,063	328,800
	(90.47)			
Affected Population (Millions)	1.151	0	18	328,800
	(1.65)			
Fire Size (Thousands of Acres)	1.278	0	29	328,800
	(1.74)			
C. Daily Climate Conditions				
Wind from NE	0.082	0	1	328,800
	(0.27)			
Wind from SE	0.211	0	1	328,800
	(0.41)			
Wind from SW	0.449	0	1	328,800
	(0.50)			
Wind from NW	0.258	0	1	328,800
	(0.44)			
Wind Speed (mph)	8.379	1	43	328,800
	(4.25)			
Max Temperature (F)	75.719	17	122	328,800
	(14.19)			
Min Temperature (F)	49.351	-7	91	328,800
	(10.99)			
Relative Humidity (%)	33.614	1	100	328,800
	(18.37)			
Vapor Pressure Deficit (kPa)	1.159	0	6	328,800
	(0.80)			
Cumulative Precipitation (mm)	1.522	0	146	328,800
	(6.24)			
Reference Alfalfa Evapotranspiration (mm)	5.458	0	20	328,800
	(2.66)			
Reference Grass Evapotranspiration (mm)	4.063	0	13	328,800
	(1.99)			
Burning Index	34.944	0	145	328,800
	(19.87)			
Number of Circuit Clusters in the Sample	300.000			

Notes: Summary statistics from a sample of 300 circuits operated by Pacific Gas and Electric, Southern California Edison, and San Diego Gas and Electric between 2018-2020. Variables related to power shutoffs were collected from the California Public Utility Commission PSPS post-season reports. Variables related to expected liability, population, and fire size are outputs from Elmfire, a state-of-the-art wildfire simulation model (Lautenberger 2013). Daily climate conditions were collected from gridMET (Abatzoglou 2013). The number of circuits refers to the total number of distribution circuit clusters included in the sample.

Table 2: Effect of Expected Liability on Shutoff Probability

Dependent Variable: Shutoff Indicator	(1)	(2)	(3)	(4)
Above Median x Log(Liability)	0.03050	0.03053	0.03058	0.03022
Line Miles Affected	(0.00869)	(0.00869)	(0.00868)	(0.00849)
Above Median Line Miles Affected	0.25423	0.24940	0.24937	0.22346
	(0.01604)	(0.01580)	(0.01580)	(0.01516)
Log(Liability)	-0.00306	-0.00221	-0.00186	-0.00302
	(0.00441)	(0.00426)	(0.01480)	(0.01384)
Log(Affected Population)	-0.00219	-0.00414	0.03000	0.02595
	(0.00306)	(0.00304)	(0.01641)	(0.01582)
Log(Predicted Fire Size)	0.00239	0.00022	-0.03764	-0.03285
	(0.00404)	(0.00393)	(0.01836)	(0.01736)
Wind Speed Quartile 4		0.03654	0.03765	0.02610
		(0.00598)	(0.00605)	(0.00726)
Max Temperature Quartile 4		-0.03170	-0.03136	-0.02651
		(0.00611)	(0.00610)	(0.00836)
Relative Humidity Quartile 1		0.02847	0.02802	0.02797
		(0.00431)	(0.00429)	(0.00525)
Precipitation Quartile 1		0.00765	0.00850	0.00701
		(0.00323)	(0.00340)	(0.00455)
Vapor Pressure Deficit Quartile 1		-0.01558	-0.01539	-0.01208
		(0.00271)	(0.00278)	(0.00305)
Grass Evapotranspiration Quartile 4		-0.03407	-0.03382	0.01026
		(0.00823)	(0.00822)	(0.00995)
Burning Index Quartile 4		0.02363	0.02363	0.01028
		(0.00558)	(0.00558)	(0.00620)
Alfalfa Evapotranspiration Quartile 4		0.04706	0.04712	0.02212
		(0.01042)	(0.01041)	(0.01062)
Controls		x	x	x
Circuit FE			x	x
Time FE				x
Mean of Dep. Var	0.006	0.006	0.006	0.006
Observations	318,631	318,631	318,631	318,631

Notes: Point Estimates and standard errors associated with the 95% confidence level from a regression of a binary indicator for an active shutoff at circuit i on day t on the interaction between logged, demeaned expected liability and an indicator for whether total miles of power lines affected by ongoing shutoffs was greater than the median observed for each utility between 2018 and 2020. Controls include logged, demeaned expected population affected by a fire and expected fire size as well as binary indicator variables for the specified quartile of climate characteristics observed at each circuit for each day between 2018 and 2020. Standard errors are clustered at the circuit level.

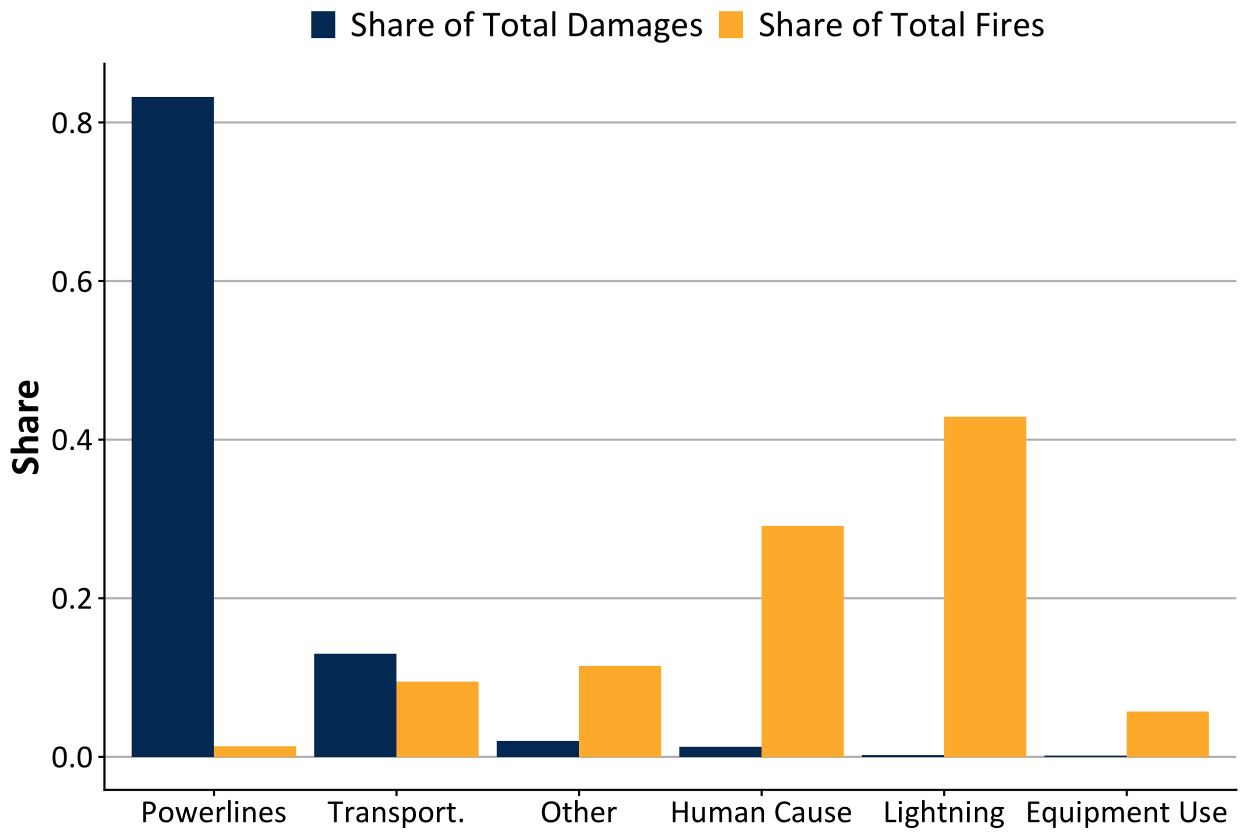
Table 3: Robustness: Two and Five Day Forecasts of Expected Liabilities

Dependent variable: Shutoff Indicator	Main Model (1)	2 Day Forecast (2)	5 Day Forecast (3)
Above Median Line Miles Affected	0.22346	0.22490	0.22863
	(0.01516)	(0.01567)	(0.01725)
Log(Liability)	-0.00030	-0.00102	-0.00124
	(0.00138)	(0.00054)	(0.00060)
Above Median Line Miles Affected x Log(Liability)	0.03022	0.03044	0.03640
	(0.00849)	(0.00872)	(0.00958)
Log(Affected Population)	0.02595	0.02430	0.02501
	(0.01582)	(0.01465)	(0.01378)
Log(Predicted Fire Size)	-0.00328	-0.00248	-0.00250
	(0.00174)	(0.00144)	(0.00135)
Wind Speed Quartile 4	0.02610	0.02720	0.02429
	(0.00726)	(0.00716)	(0.00688)
Max Temperature Quartile 4	-0.02651	-0.03138	-0.03507
	(0.00836)	(0.00903)	(0.00985)
Relative Humidity Quartile 1	0.02797	0.02969	0.02597
	(0.00525)	(0.00534)	(0.00533)
Precipitation Quartile 1	0.00701	0.00730	0.00571
	(0.00455)	(0.00462)	(0.00462)
Vapor Pressure Deficit Quartile 1	-0.01208	-0.01224	-0.01251
	(0.00305)	(0.00326)	(0.00326)
Grass Evapotranspiration Quartile 4	0.01026	0.00940	0.01418
	(0.00995)	(0.00961)	(0.01044)
Burning Index Quartile 4	0.01028	0.01069	0.01360
	(0.00620)	(0.00630)	(0.00601)
Alfalfa Evapotranspiration Quartile 4	0.02212	0.03017	0.02652
	(0.01062)	(0.00927)	(0.01008)
Controls	x	x	x
Circuit FE	x	x	x
Time FE	x	x	x
Mean of Dep. Var	0.006	0.006	0.006
Observations	318,631	291,291	255,624

Notes: Point Estimates and standard errors associated with the 95% confidence level from a regression of a binary indicator for an active shutoff at circuit i on day t on the interaction between logged, demeaned expected liability on day t (column 1), over the next 2 days (column 2) or over the next 5 days (column 5) and an indicator for whether total miles of power lines affected by ongoing shutoffs was greater than the median observed for each utility between 2018 and 2020. Controls include logged, demeaned expected population affected by a fire and expected fire size as well as binary indicator variables for the specified quartile of climate characteristics observed at each circuit for each day between 2018 and 2020. Standard errors are clustered at the circuit level.

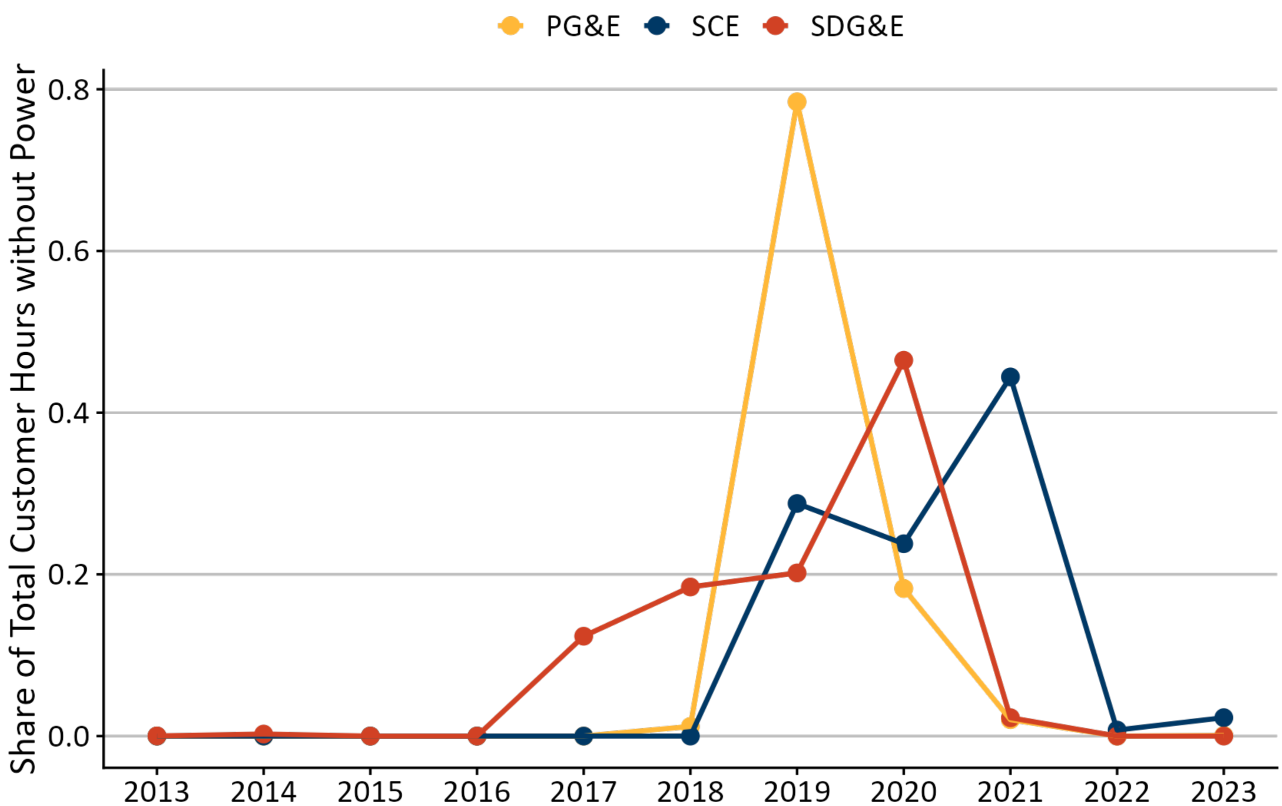
8 FIGURES

Figure 1: Share of Wildfire Ignitions (1910-2016) and Damages (2008-2019) by Source



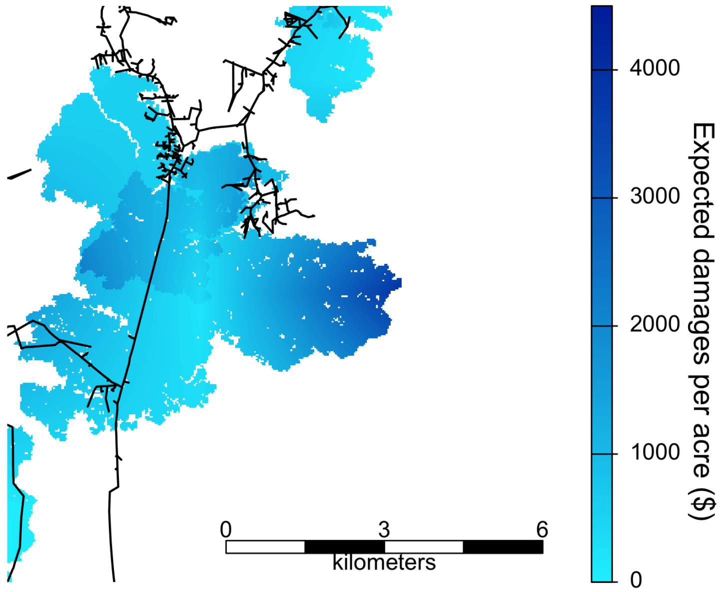
Notes: Share of total wildfire ignitions in California by cause of ignition between 1910 and 2016 are shown in yellow. The "Other" category includes fires caused by arson, debris, smoking, camping, playing with fire, railroads, lumber, equipment, and vehicles. Data are from Keeley and Syphard 2018. Share of total wildfire damages by ignition cause between 2008 and 2019 in California are shown in blue. Damages are defined as the replacement cost of homes destroyed by wildfire. The "Other" category includes fires caused by arson, debris, smoking, camping, playing with fire, railroads, lumber, equipment, and undefined cause. Data were collected by the author from CalFire historical wildfire activity data, also referred to as "redbooks."

Figure 2: Share of Total Customer Hours Impacted by Shutoff Events

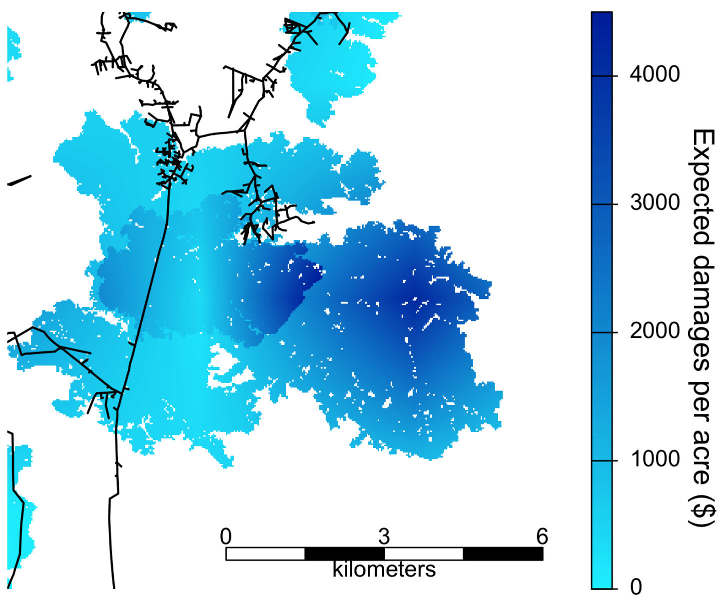


Notes: Total customer hours computed by the author from public safety power shutoff post event reports. The share is computed by dividing impacted customer hours in each year by each utility's cumulative customer hours impacted by shutoff events between 2013 and 2020. Customer hours include commercial and residential customers served by California's three largest privately-owned utilities, Pacific Gas and Electric, Southern California Edison, and San Diego Gas and Electric. Reports are available from the California Public Utility Commission.

Figure 3: Expected Damages per Acre from a Potential Fire Ignition



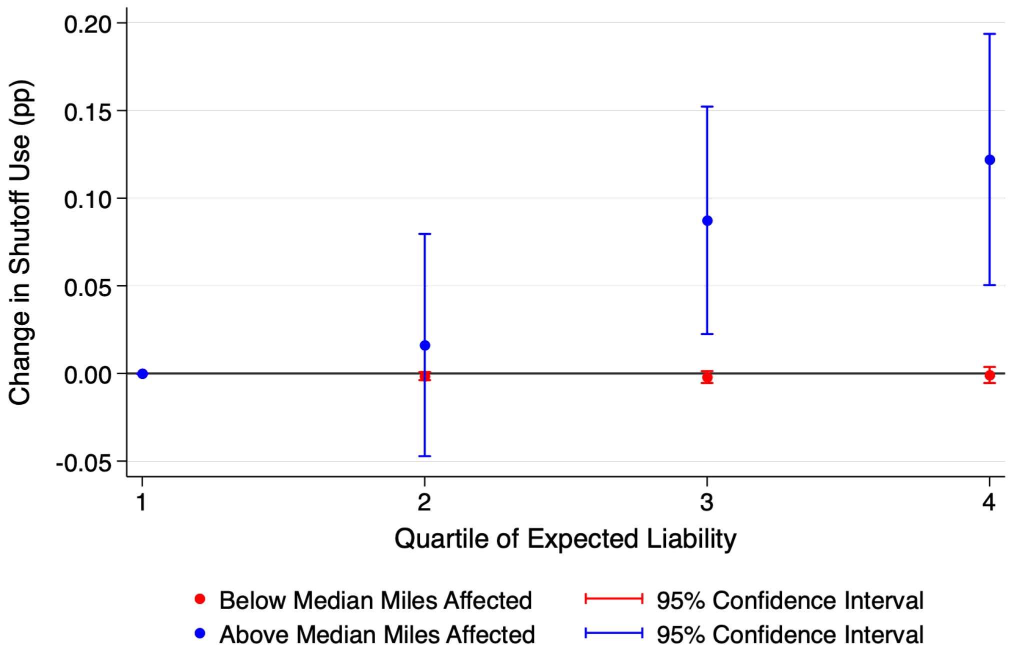
(a) May 5, 2019



(b) May 6, 2019

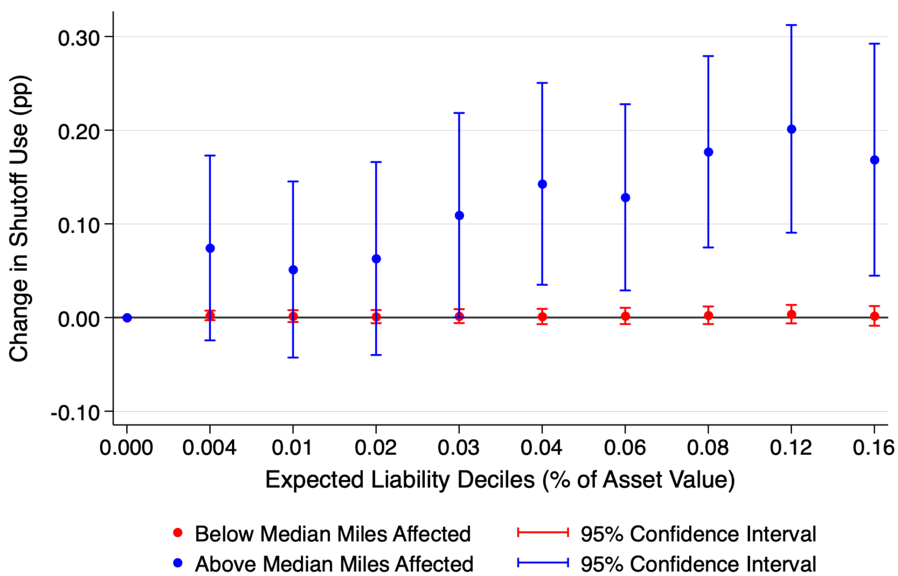
Notes: The blue area is the product of the probability that each pixel burns and property values per acre calculated from the Zillow ZTRAX database as of 2018. Burn probabilities are calculated by dividing the number of times that a pixel burned by the total number of monte carlo simulations per day (60). Fire simulations were conducted using Elmfire, an open-source model of fire spread that is widely used to measure fire risk. Lines show part of a distribution circuit operated by Pacific Gas and Electric in Northern California.

Figure 4: Shutoff Use by Quartile of Liability and Miles of Line Affected by a Preexisting Shutoff



Notes: Point estimates and associated 95% confidence intervals from a regression of an indicator for whether there is an active shutoff at circuit i on day t on the interaction between liability binned by quartile (separately for each firm) and an indicator equal to one when the power line-miles that are already shutoff prior to the shutoff decision at circuit i on day t are greater than the median amount of miles powered down for each firm.

Figure 5: Shutoff Use by Decile of Liability as a Percentage of Asset Value and Miles of Line Affected by a Preexisting Shutoff



Notes: Point estimates and associated 95% confidence intervals from a regression of an indicator for whether there is an active shutoff at circuit i on day t on the interaction between expected liability divided by each firms' total 2022 asset value binned by decile and an indicator equal to one when there are above median power line-miles that are already shutoff prior to the shutoff decision at circuit i on day t.