Prescribed Fires as a Climate Adaptation Tool: An Econometric Analysis

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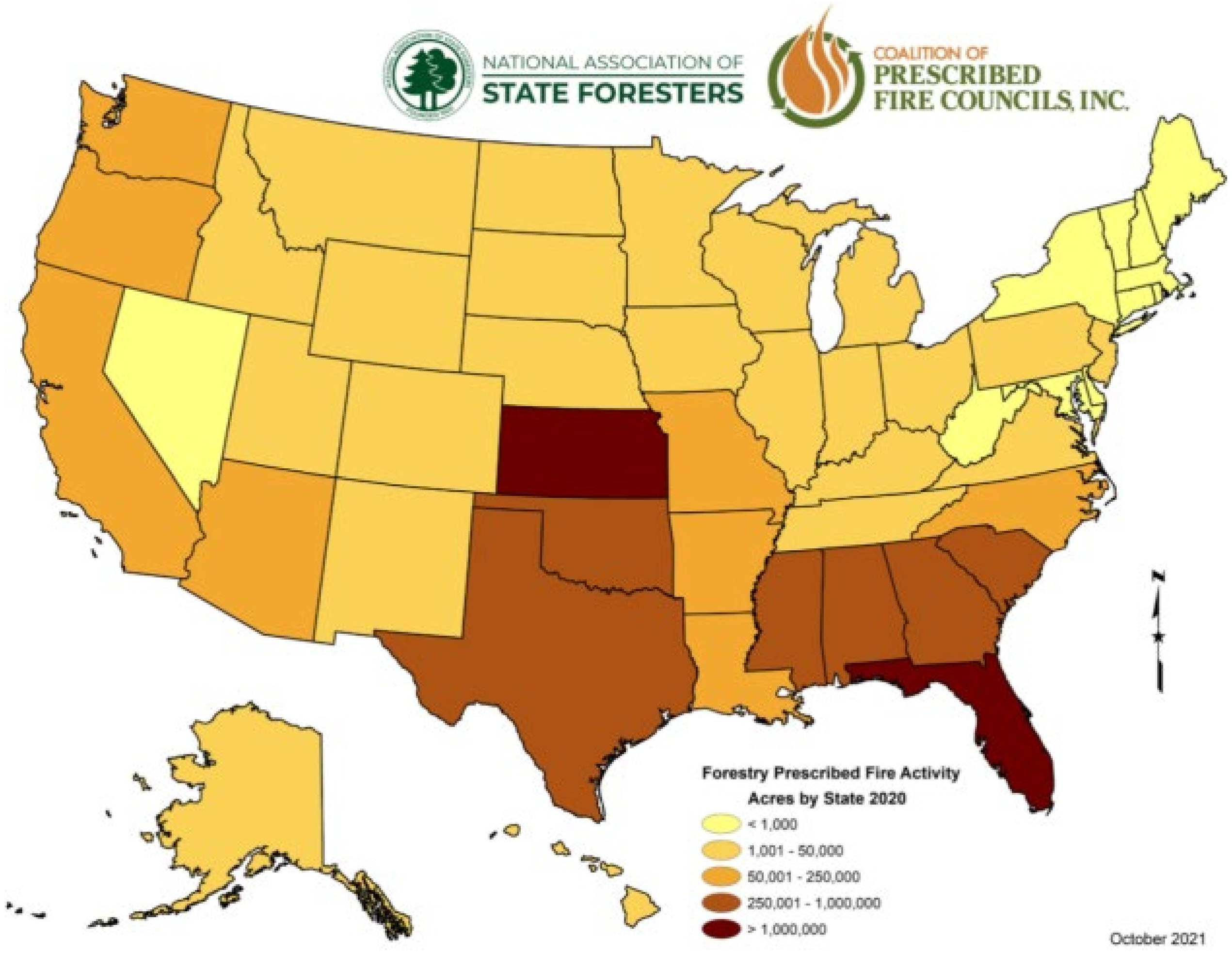
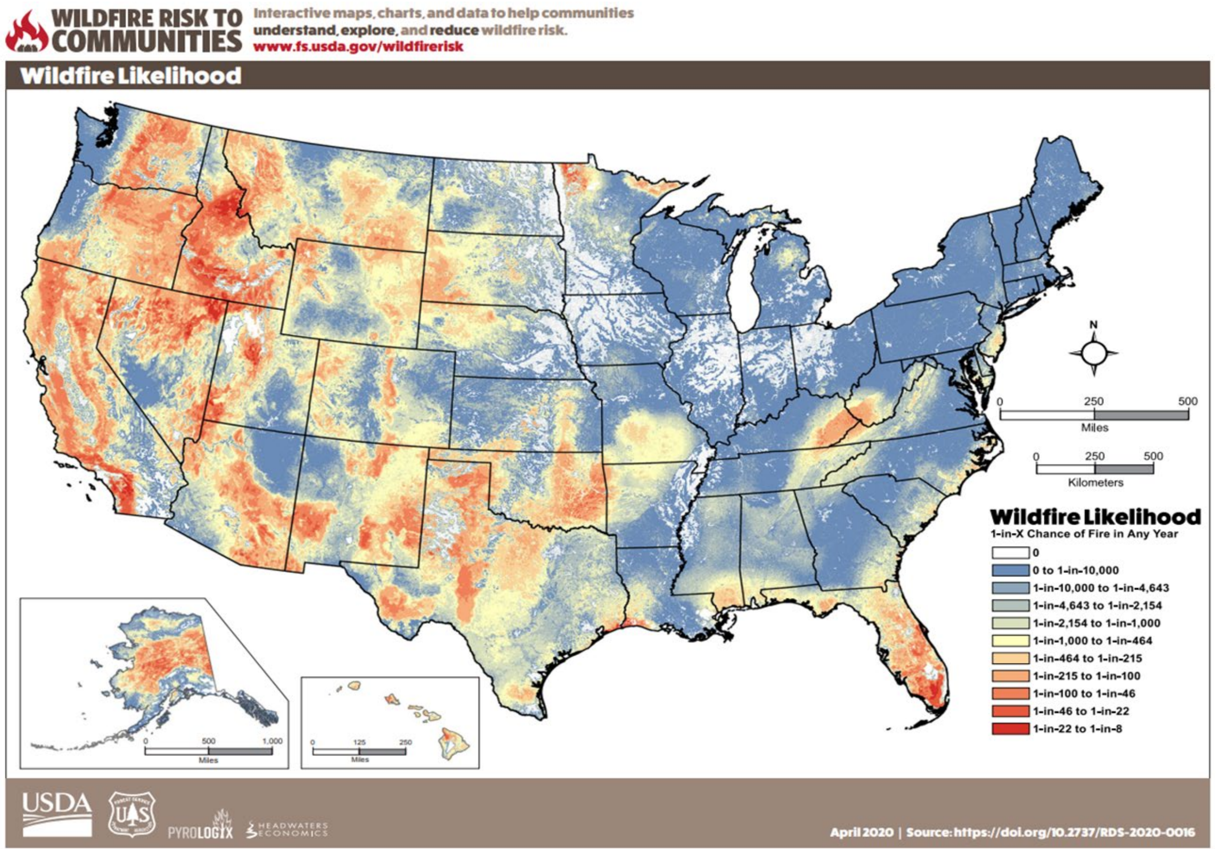
Prescribed fire



- Prescribed fires consist of controlled burns that can provide benefits:
  - Reduces hazardous fuels and fire spread
  - Promote growth of commercially valuable trees
  - Improve habitat for some wildlife species
- Prescribed fires can present challenges:
  - Air quality
  - Risk of escaped wildfire
  - Liability
- Prescribed fires are more common in the southeastern U.S.

Economic Issues and Climate Change

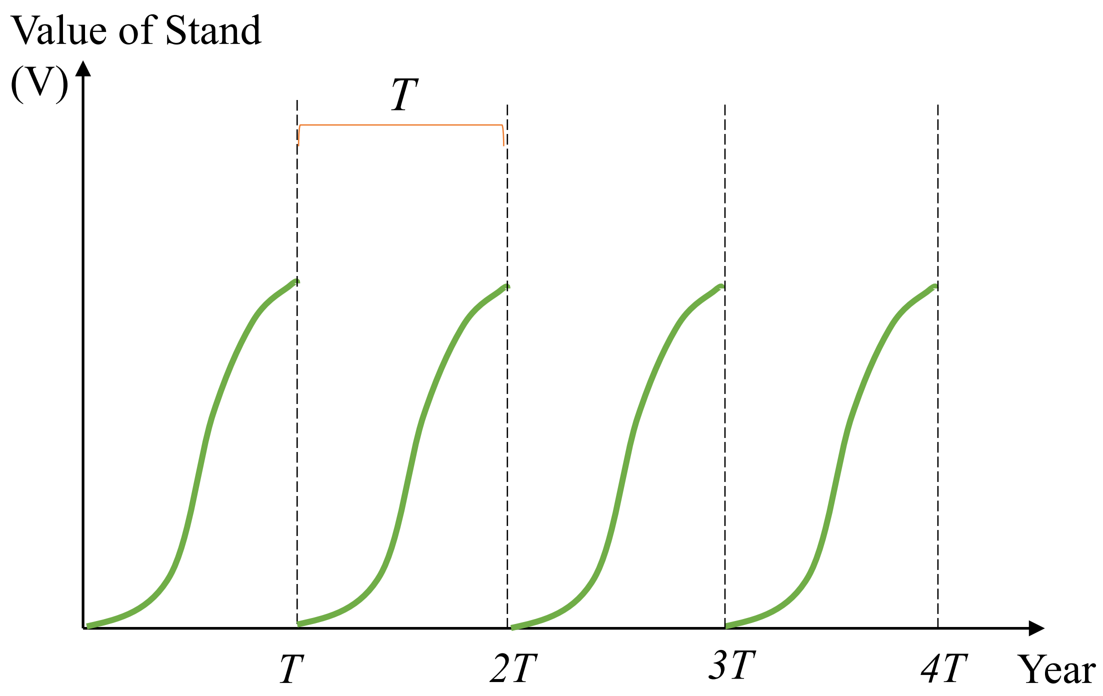
- Prescribed fires can be cast as a (costly) protection effort against wildfire
- Economic theory of costly protection of forests
  - Originating in Reed (1984; 1987) and extended by many others (e.g. Yoder 2004; Amacher et al. 2005; Lauer et al. 2017; etc.)
  - Optimal protection depends on wildfire risk (Amacher et al. 2005)
- Climate change linkage to wildfire:
  - Increasing wildfire arrival and risk (e.g. Abatzoglou and Williams 2016)
  - More frequent large wildfires are causing large economic costs, through channels like PM 2.5 (Burke et al. 2021)



Research Questions

- How is the amount of prescribed burning by private landowners related to climate change? We want to describe the adaptation channel.
- Can we derive econometric evidence for prescribed fire as a climate adaptation tool:
  - The link between climate / wildfire risk on prescribed burning by private landowners?
  - The link between climate / prescribed burning on wildfire occurrence?

Theoretical foundation - Faustmann



Faustmann rotation model

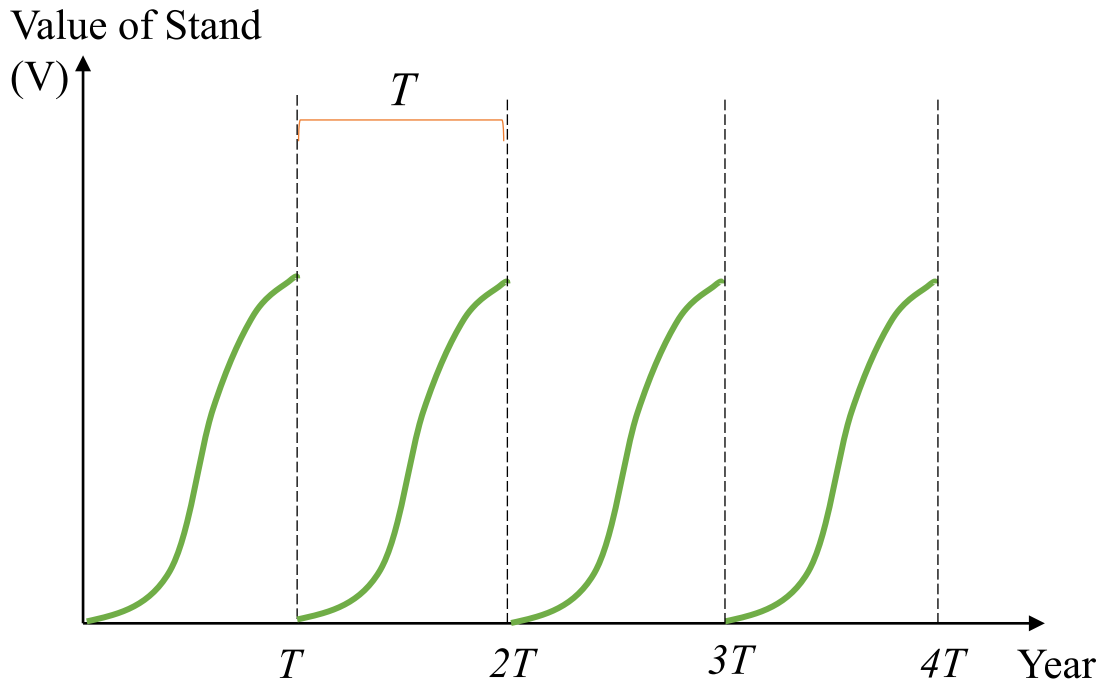
- Suppose landowner maximizes stand value V by choosing the optimal rotation length T, then the value of bare timberland is:

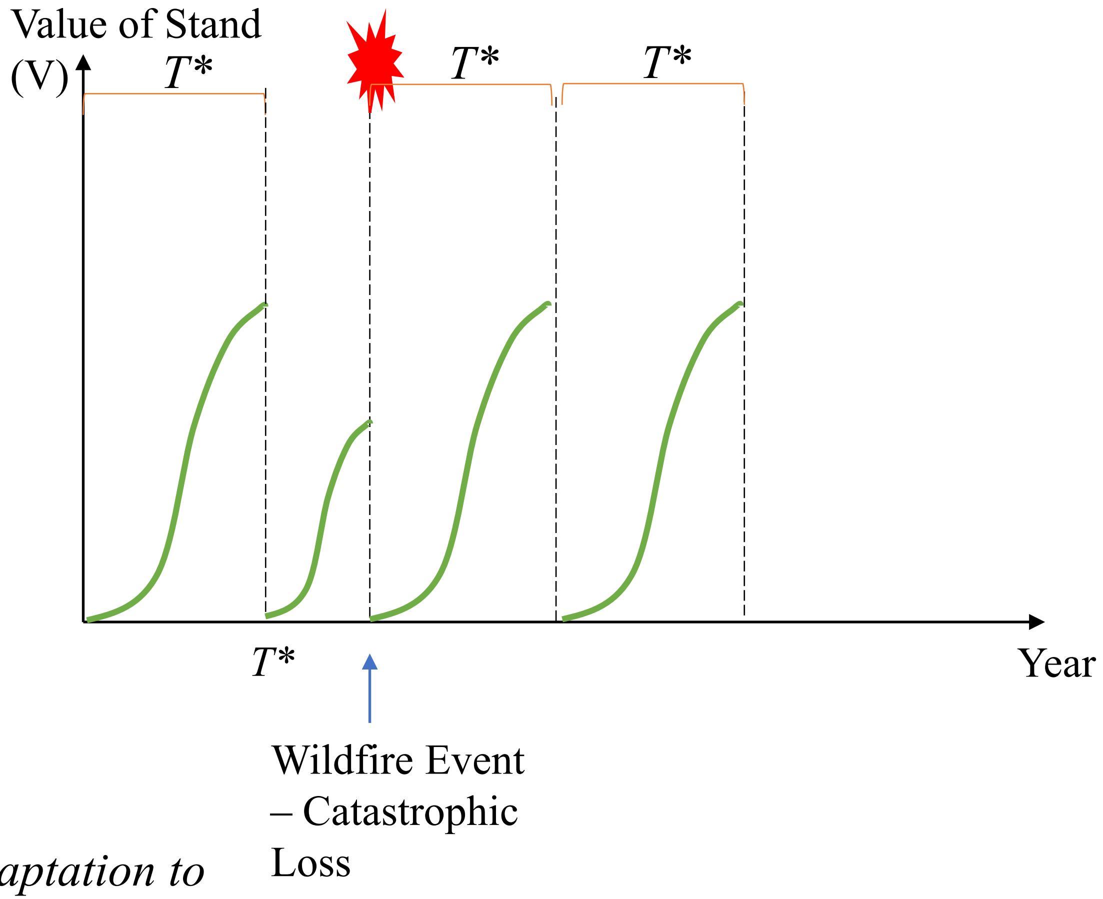
$$V^{bare} = \frac{[P*F(T)-C]e^{-rT}}{1-e^{-rT}}$$

Where *F(t) is* tree volume at time *t, P* is constant per-unit stumpage prices, C is a regeneration cost, and *r* is the discount rate.

Theoretical foundation – Reed (1984)

The value of the stand and management behavior change with wildfire risk





Management Adaptation to wildfire: T<T*

Theoretical foundation – Reed (1984)

Reed (1984) extended the Faustmann model to incorporate fire risk

- Suppose fire occurs independently at an average rate of λ per unit time (a Poisson process), and no any salvage value once fire arrives. Then the value of bare timberland becomes:

$$V^{bare} = \frac{(r+\lambda)[P*F(T)-c_1]e^{-(r+\lambda)T}}{r(1-e^{-(r+\lambda)T})} - \frac{\lambda}{r}c_2$$

VS

Faustmann rotation model

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★**Poisson fire risk parameter *λ* implicitly increases the landowners' discount rate, leading to a shorter rotation age.**

Where *F(t) is* tree volume at time *t, P* is constant per-unit stumpage prices, C is a regeneration cost, and *r* is the discount rate.

Theoretical foundation – Costly Protection

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Costly Protection Literature:

- $\boldsymbol{\lambda}$ can be altered by protection effort
- E.g. Reed 1987; Yoder 2004; Amacher et al. 2005; Lauer et al. 2017

Prescribed burning and climate affect wildfire risk $\boldsymbol{\lambda}$

- Suppose λ is an increasing function of the climate variable (C) and a decreasing function of prescribed burning effort (PB):

$$\lambda(C, PB) \Rightarrow \lambda'(C) > 0 \; and \; \lambda'(PB) < 0$$

Costly Protection (Following Amacher et al.'s (2009) depiction)

- The value of bare timberland is:

$$V^{bare} = \frac{[r+\lambda(C,PB)][P*F(T)-c_1(PB)]e^{-[r+\lambda(C,PB)]T}}{r(1-e^{-[r+\lambda(C,PB)]T})} - \frac{\lambda(C,PB)}{r}c_2$$

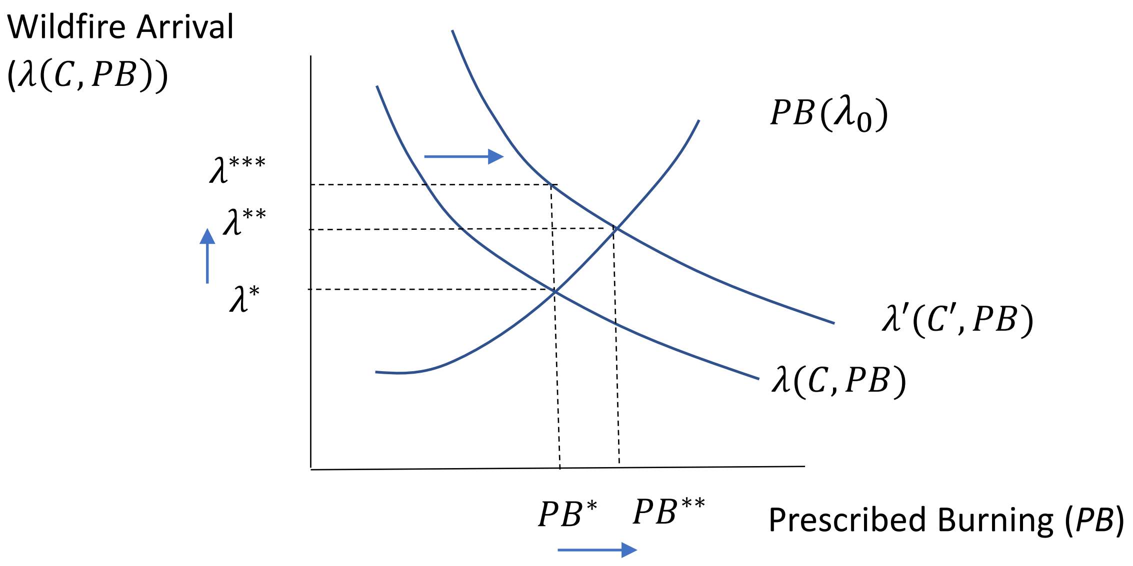
where $c_1'(PB) > 0 \; and \; c_1''(PB) > 0$

Theoretical foundation – Describing Prescribed Burning as Climate Adaptation

Optimal Protection

- Suppose $\lambda(C, PB) = \frac{1}{1+\exp(\alpha_0 C + \alpha_1 PB)}$, where $\alpha_0 < 0, \alpha_1 > 0$
- And $\lambda_0(C) = \lambda(C, PB = 0)$ is fire risk in the absence of protection
- Optimally adapting landowner maximizes land value (V^{bare}) by solving for rotation length (T) and prescribed burning (PB).

*Wildfire risk (λ) and prescribed burning (PB) are simultaneously determined and are altered by climate change



λ^{***}- λ^{**}= lower wildfire arrival that arises from prescribed burning adaptation (PB^{**}- PB^{*})

Theoretical foundation – Describing Prescribed Burning as Climate Adaptation

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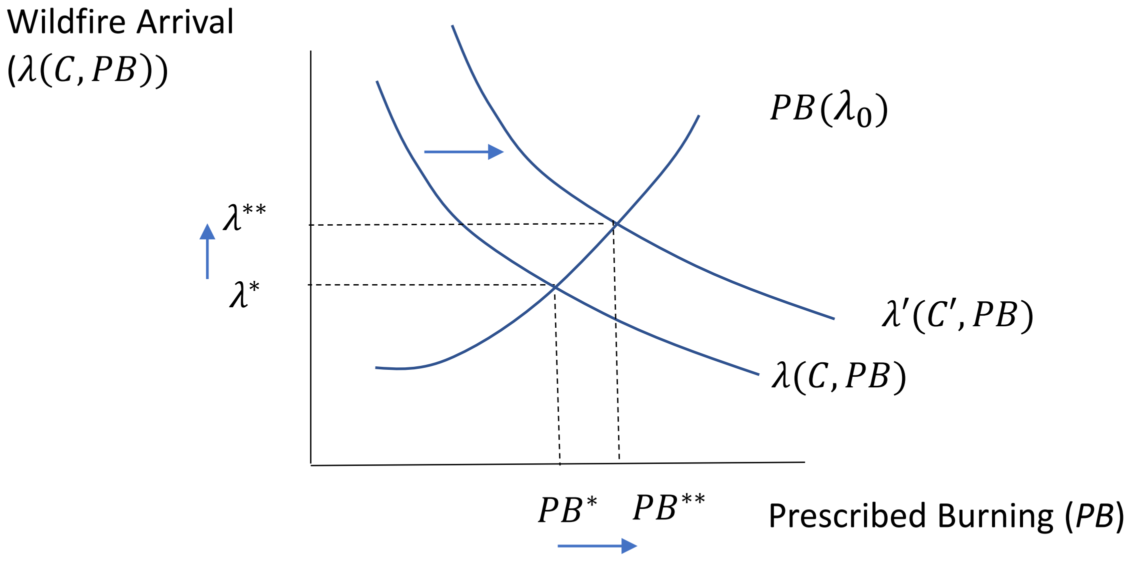
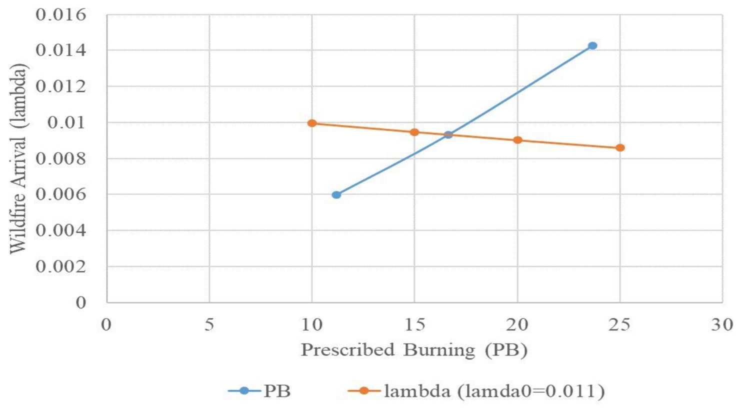


Numerical Example from FL panhandle



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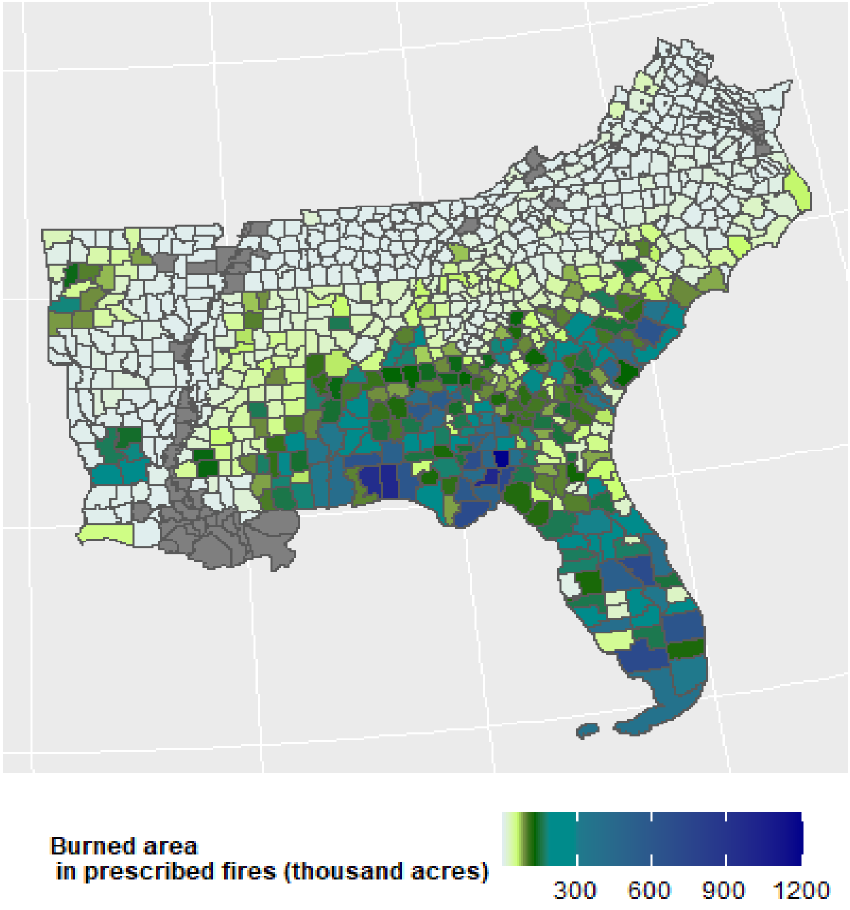
Empirical analysis

- Task:
  - Estimate prescribed burning effort as a function of wildfire risk and climate
  - Estimate wildfire outcomes as a function of prescribed burning and climate
- Key data (aggregated to county):
  - Non-agricultural prescribed burning panel data for 10 southeastern states, collected from fire permit records by Tall Timbers Research
  - MTBS wildfire data; Short's (2022) wildfire data
  - FIA database
  - Panel dataset from 2010-2021
    - N=801 counties; T=12 years
    - N*T=9,612 observations



Variable	Mean	St. Dev.
# Prescribed Burns (PB)	211.98	346.05
Prescribed Burn acres (2-year roll. avg.)	5839.4	11837
Wildfire acres (2-year roll. avg.)	424.62	5465.8
Wildfire acres (20-year roll. avg.)	522.46	3963.5

Key state level regulations in prescribed burning applications

States	Certified Burner	Written Prescription	Permit	Smoke Plan	Funding/Cost Share
AL	Y	Y	Y	N (voluntary)	Y
AR	N	N	N (notice only)	N (voluntary)	Y
FL	Y	Y	Y	Y	Y
GA	Y	N	Y	Y	Y
LA	Y	Y	N	N (voluntary)	Y
MS	Y	Y	Y	N (voluntary)	Y
NC	Y	Y	Y	Y	Y
SC	Y	Y	N (notice only)	Y	Y
TN	Y	Y	Y	N	Y
VA	Y	Y	N (notice only)	Y	Y

Econometric specification

- Prescribe burning (PB) equation for county c in time t,
  - $PB_{ct} = \gamma_0 + \gamma_1 WB_{ct} + \gamma_2 WB_{ct} * R_{s(c)} + \gamma_3 C_{ct} + \gamma_4 F_{ct} + \alpha_c + \nu_{st} + \varepsilon_{ct}$
- Wildfire burn (WB) equation for county c in time t,
  - $WB_{ct} = \eta_0 + \eta_1 PB_{ct} + \eta_2 C_{ct} + \eta_3 F_{ct} + \tau_c + \xi_{ct}$

  - Variables (c: county, t: time, s: state):
    - PB_{ct}: prescribed burning acreage
    - WB_{ct}: wildfire burn acreage
    - $R_{s(c)}$: state regulations dummies for prescribed burning
    - C_{ct}: climate (vapor pressure deficit, mean temp, mean precip.)
    - F_{ct}: Forestry characteristics (avg. volume, site class, stand age, slope, elev, ownership)
    - α_c, τ_c: county fixed effects
    - ν_{st}: state-by-year fixed effects

Econometric specification

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  - How to measure WB_{ct} and C_{ct} as independent variables?
    - Short term: rolling average of two years preceding year t (e.g. weather)
    - Long term: rolling average of twenty years preceding year t (e.g. climate)
  - Instruments:
    - PB equation: WB instrumented with naturally caused wildfires (e.g. by lightning)
    - WB equation: PB instrumented with forest sector wages, deer harvest counts
  - Specify as a log-log model

Key econometric results in elasticity form

- Marginal effects of recent wildfire acreage on prescribed burning

	Short-term wildfire	Long-term wildfire
States with burn permit not required	1.81*** (0.468)	1.02*** (0.171)
States with burn permit required	0.314* (0.170)	0.425*** (0.077)

- Marginal effects of climate (vapor pressure deficit) on prescribed burning

	Short-term weather	Long-term climate
Average	4.04*** (1.023)	7.613*** (1.272)

Notes: standard errors in parentheses
*p<0.1; **p<0.05; ***p<0.01

Key econometric results in elasticity form

- Marginal effects of prescribed burning (prior 2 years) on wildfire

	No IVs	IV=forest sector wage	IV=forest sector wage; deer harvest
Average	0.001 (0.001)	-0.226** (0.111)	-0.208** (0.099)

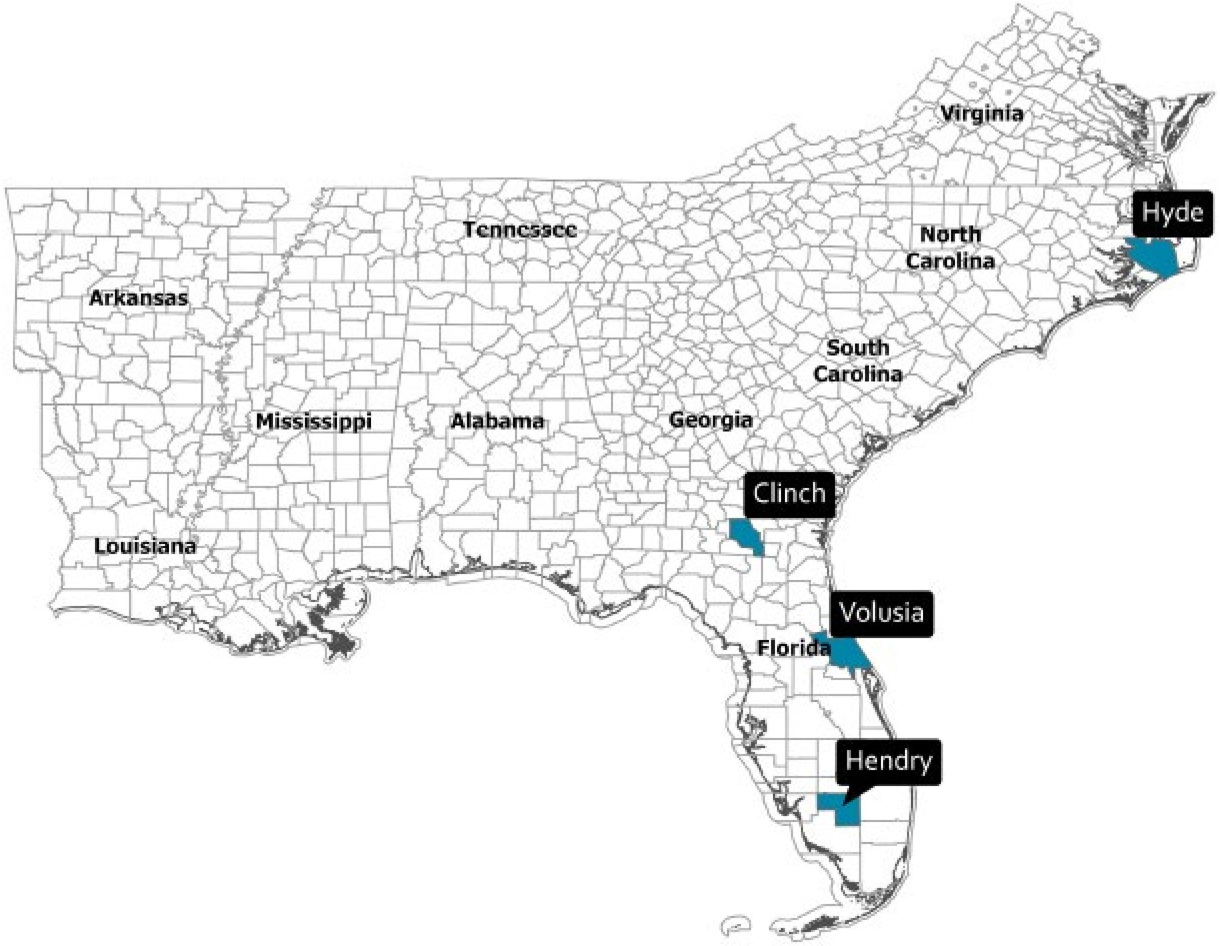
- Marginal effects of climate (vapor pressure deficit) on wildfire

	No IVs	IV=forest sector wage	IV=forest sector wage; deer harvest
Average	0.996** (0.399)	3.779*** (0.874)	4.338** (1.085)

Notes: standard errors in parentheses
*p<0.1; **p<0.05; ***p<0.01

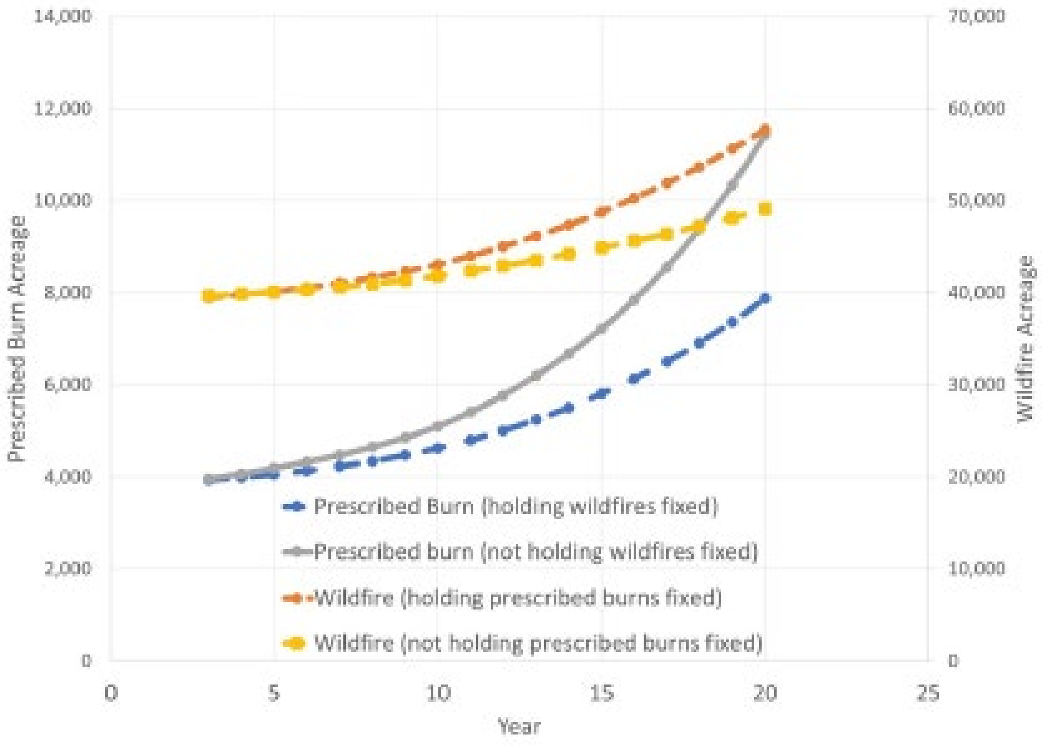
Simple climate change simulation

- How does projected changes in climate (higher VPD) affect equilibrium prescribed burning and wildfire?
  - Climate projections indicate VPD increases by 12 percent on average (2 to 32 percent range) across study region by 2050.
  - This warmer/drier projection should increase both wildfire and prescribed burning adaptation by landowners.



Simple climate change simulation

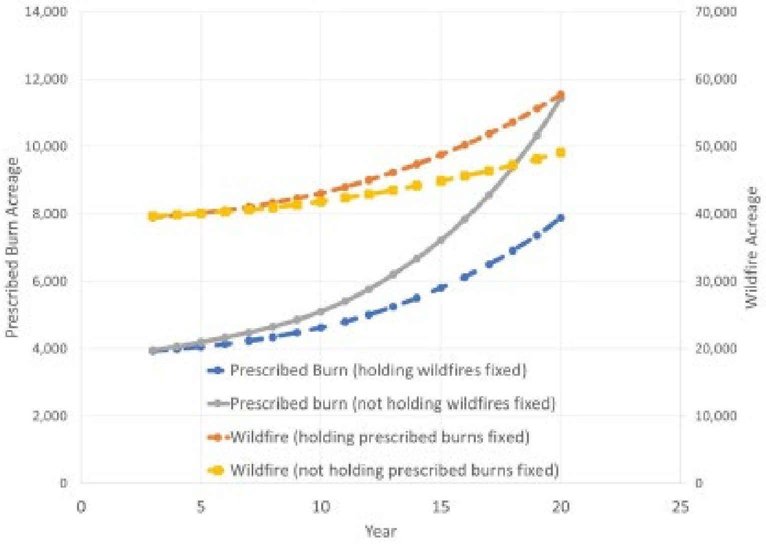
- How does projected changes in climate (higher VPD) affect equilibrium prescribed burning and wildfire?
  - Both wildfire (yellow) and prescribed burns (gray) increase.
  - In 20 years, wildfire acreage would have been larger (by ~10k acres) without prescribed burning adaptation (orange line).
  - Prescribed burning would have been lower if wildfire acreage had not increased (blue line).



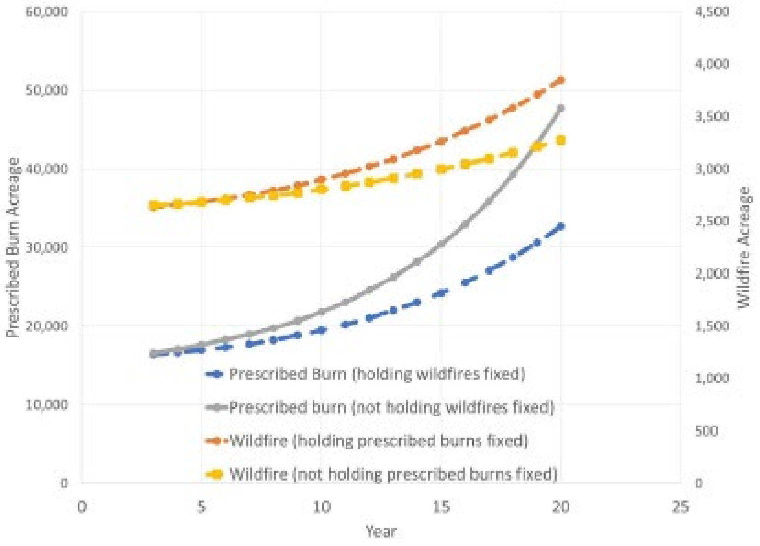
(a) Clinch County

Simple climate change simulation

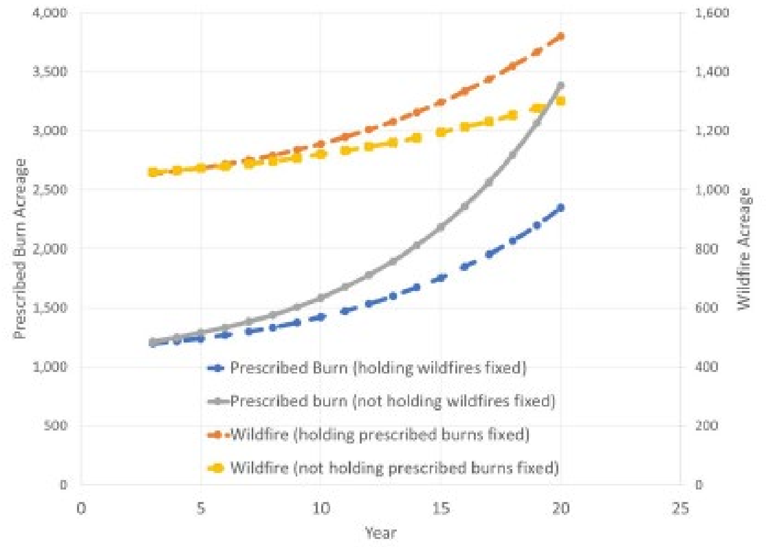
- How does projected changes in climate (higher VPD) affect equilibrium prescribed burning and wildfire?
  - Same pattern holds for the four representative counties.
  - Scale differs (see change in axes)
    - Some counties have more acreage prescribed burned than in wildfire (e.g. Volusia Co. FL)
    - Some counties have more acreage in wildfire than prescribed burn (e.g. Clinch Co. GA)



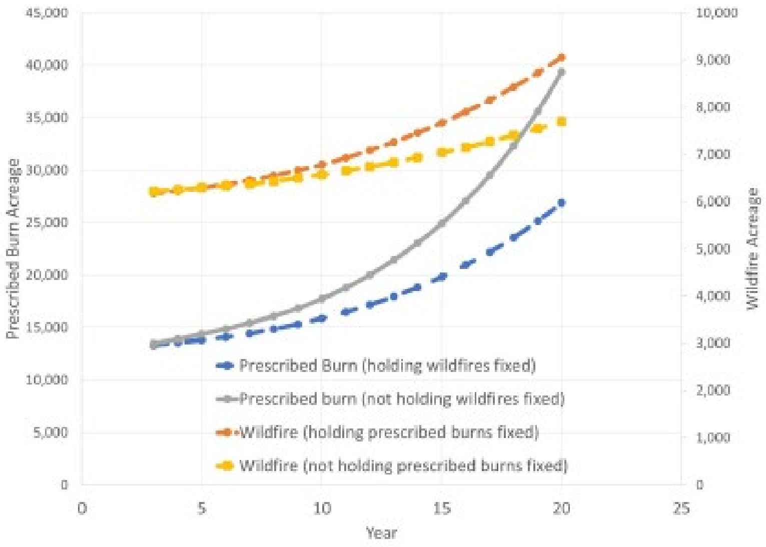
(a) Clinch County



(b) Volusia County



(c) Hyde County



(d) Hendry County

Conclusion

- Simple extension to existing theory suggests prescribed burning is a climate adaptation strategy that interacts with wildfire outcomes.
- Empirical evidence from a 12-year panel across 12 southeastern U.S. states suggests:
  - Landowners respond to recent wildfire with more prescribed burning
    - Elasticity $\approx$ 1.8 in states without mandated burn permits
    - Elasticity $\approx$ 0.3 in states with mandated burn permits
  - Prescribed burning acreage reduces wildfire acreage (elasticity $\approx$ 0.21)
  - Warmer and drier climate change (VPD) increase both wildfire (elasticity $\approx$ 4.3) and prescribed burning (elasticity $\approx$ 4), and prescribed burning adaptation slows growth in wildfire acreage.

Thank you

Questions / comments welcome

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