Virtual Seminar on Climate Economics

Federal Reserve Bank of San Francisco

Organizing Committee:
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The Fiscal Costs of Climate Change in the United States

Lint Barrage
FRBSF Virtual Seminar on Climate Economics

U.C. Santa Barbara & NBER

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Introduction

- Climate change's fiscal impacts and policy implications
   i. Existing programs (e.g., healthcare, wildfire suppression)
   ii. Public adaptation (e.g., coastal infrastructure)
   iii. Revenue impacts (e.g., employment, output effects)

  Growing policy concern (e.g., U.S. GAO "High Risk" List)

- Benchmark Integrated Assessment Models (IAMs, e.g. DICE, Nordhaus, 1992, 2017; FUND, Anthoff and Tol, 2014; Golosov et al., 2014, etc.) typically do not consider/distinguish fiscal costs as such

- However, if gov't raises revenues with *distortionary* taxes:
  - Socially costly to raise, divert public funds
  - Fiscal constraints may limit adaptation, increase damages
  - Show: Change structure of optimal carbon price

This Paper

- Formalizes, aggregates, quantifies fiscal cost effects in IAM

1. Set up macro climate-economy model with fiscal impacts
   $\Rightarrow$ Theoretical optimal policy implications

2. Bottom-up quantification of fiscal impacts
   $\Rightarrow$ Prior literature, data, forecasts

3. Quantitative U.S. fiscal policy climate-economy model
   $\Rightarrow$ Welfare, fiscal implications of carbon pricing

Literature

- Climate-economy models, IAMs (Nordhaus, 1992, 2017; Manne, Richels, 2005; Anthoff, Tol, 2014; Golosov et al., 2014; vd Ploeg, Withagen, 2014; etc.), Adaptation (e.g., Hope, 2006; Tol, 2007; deBruin et al. 2009; Bosello et al., 2010; Agrawala et al. 2010; Belfiori 2015; Fried 2019)
  - Distortionary taxes: Barrage (2020)
  - Here: +Fiscal climate impacts, U.S. model
- Pollution mitigation and distortionary taxes (Sandmo 1975, Bovenberg, de Mooij 1994; Goulder 1995; Bovenberg Goulder, 1996; Williams 2002, Babiker et al. 2003; Goulder et al. 2014; Fried et al. 2018; etc.)
  - Here: Integrated assessment, output & public spending impacts
- Fiscal impacts of weather events (Noy, Nualsri, 2011; Deryugina, 2017), climate change (e.g., IMF, 2008; CBO, 2016; OMB, 2016)
  - Here: Integrate into IAM, analyze implications

Talk Outline

1. Introduction
2. Model
   - **Setup**
   - Qualitative Results
3. Quantification
   - Existing Public Program Costs
   - Sea Level Rise Adaptation
   - Rest
4. Numerical Results
5. Conclusion

Households

- Infinitely-lived, rep. household with well-behaved **preferences** over consumption C_t, labor L_t, climate change T_t:

$$U_0 \equiv \sum_{t=0}^{\infty} \beta^t U(C_t, L_t, T_t, \Lambda_t^u)$$

- where $\Lambda_t^u \sim$ adaptive capacity against climate utility impacts (e.g., damages to national parks)

- Further assume:

$$U(C_t, L_t, T_t, \Lambda_t^u) = v(C_t, L_t) + h[(1 - \Lambda_t^u) T_t]$$

Household Flow Budget Constraint

$$
\begin{aligned}
& C_t + \rho_t B_{t+1} + K_{t+1} \\
\leq \quad & w_t(1-\tau_{lt})L_t + \left\{1 + (r_t - \delta(SLR_{t,}, \Lambda_t^{slr}))(1-\tau_{kt})\right\} K_t \\
& + B_t + \Pi_t + G_t^T(T_t)
\end{aligned}
$$

$B_{t+1} \sim$ bond purchases
$\rho_t \sim$ price of one-period bond
$K_{t+1} \sim$ private capital stock
$w_t \sim$ wage rate
$\tau_{lt} \sim$ labor income tax rate
$r_t \sim$ return on capital
$\tau_{kt} \sim$ capital income tax rate

$\delta() \sim$ depreciation rate
$SLR_t \sim$ sea level rise
$\Lambda_t^{slr} \sim$ adaptive capacity
$\Pi_t \sim$ profits from energy sector
$G_t^T(T_t) \sim$ gov't transfers

Production

- **Final Good:** Production CRS in L_{1t}, K_{1t} and energy E_t

$$
\begin{aligned}
Y_t &= F_1(A_{1t}, L_{1t}, K_{1t}, E_t, T_t, \Lambda_t^y,) \\
&= (1 - D(T_t)(1 - \Lambda_t^y)) \cdot A_t \widetilde{F}_1(L_{1t}, K_{1t}, E_t)
\end{aligned}
$$

  - $D(T_t)$ gross climate damages, Λ_t^y adaptive capacity

- **Energy Input:** CRS extraction technology:

$$
E_t = F_2(A_{Et}, L_{2t}, K_{2t})
$$

  - Provide fraction μ_t from clean tech. at extra cost $\Theta_t(\mu_t E_t)$

Model Overview: Government

- **Expenditures:** Must raise revenues to finance
  - Household transfers $G_t^T(T_t) \geq 0$
  - Consumption: $G_t^C(T_t)$
  - Initial debt B_0
- May choose to fund $(\lambda_t^y, \lambda_t^u, \lambda_t^{slr})$ adaptation:

$$\Lambda_t^i = f^i(\{\lambda_s^i\}_{s=0}^t) \text{ for } i \in \{u, y, slr\}$$

- **Revenues**:
  - Linear taxes on labor income τ_{lt}
  - Linear taxes on net-of-depreciation capital income τ_{kt}
  - Excise taxes on energy inputs τ_{It}
  - Excise taxes on carbon emissions τ_{Et}
  - One-period bonds
- **Marginal Cost of Public Funds** (MCF_t): Welfare cost of raising extra dollar of gov't revenue
  - Ratio of the public / private marginal utility of income

Climate

- **Temperature change** depends on U.S. carbon emissions $E_t^M \equiv (1-\mu_t)E_t$ plus rest-of-world (ROW) emissions E_t^{ROW} :

$$T_t = F_t(E_0^M + E_0^{ROW}, E_1^M + E_1^{ROW} ..., E_t^M + E_t^{ROW})$$

- Benchmark: E_t^{ROW} exogenous, but also consider ROW response elasticity to U.S. mitigation

- **Sea level rise** depends on history of temperature change (Rahmsdorf, 2007):

$$SLR_t = G(SLR_0, T_1, T_2, ... T_t)$$

Climate Impacts and Policy: Summary

- Climate Change Impact Channels:
  - [Standard]: Production: $Y_t = D(T_t) \cdot F(.)$
  - Utility: $U(C_t, L_t, T_t)$
  - Capital depreciation: $\delta(SLR_t, .)K_t$
  - [New]: Government consumption: $G_t^C(T_t)$
  - [New]: Government transfers: $G_t^T(T_t)$

- Government Policy Choices:
  - [Standard]: Carbon tax τ_{Et}
  - [COMET]: Capital, labor, taxes τ_{kt}, τ_{lt}; bonds B_t^G, gov't spending G_t^C, G_t^T ...
  - [New]: Public adaptation $\Lambda_t^y, \Lambda_t^u, \Lambda_t^{slr}$

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Optimal Mitigation

Define:

$$M_j \equiv \begin{cases} 1 & \text{if } j = 0 \\ \beta^j \prod_{m=1}^{j} \frac{1}{(1+r_{t+m}-\delta_{t+m})} & \text{o.w.} \end{cases}$$

Optimal Mitigation

Result 1 *The optimal carbon tax in period $t > 0$ is implicitly defined by:*

$$
\begin{aligned}
\tau^*_{Et} \quad = \quad & \text{PV [Output Impacts]} \\
& + \left(\frac{1}{MCF_t}\right) \text{PV [Utility Impacts]} \\
& + \text{PV[Sea Level Rise Impacts]} \\
& + \text{PV[Gov't Consumption Impacts]} \\
& + \left(\frac{MCF_t - 1}{MCF_t}\right) \text{PV[Gov't Transfer \& Offer Curve Impacts]}
\end{aligned}
$$

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\tau^*_{Et} \quad = \quad & \sum_{j=0}^{\infty} M_j \cdot \frac{-\partial Y_{t+j}}{\partial T_{t+j}} \cdot \frac{\partial T_{t+j}}{\partial E_t^M} \\
& + \left(\frac{1}{MCF_t}\right) \text{PV [Utility Impacts]} \\
& + \text{PV[Sea Level Rise Impacts]} \\
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& + \text{PV[Sea Level Rise Impacts]} \\
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*Bovenberg and van der Ploeg (1994), Bovenberg and Goulder (1996), ...

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& + \text{PV[Gov't Consumption Impacts]} \\
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& + \text{PV[Sea Level Rise Impacts]} \\
& + \sum_{j=0}^{\infty} M_j \cdot \frac{\partial G_{t+j}^{C}}{\partial T_{t+j}} \cdot \frac{\partial T_{t+j}}{\partial E_t^{M}} \\
& + \left(\frac{MCF_t - 1}{MCF_t}\right) \text{PV[Gov't Transfer \& Offer Curve Impacts]}
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$$+\text{PV[Sea Level Rise Impacts]}$$

$$+\text{PV[Gov't Consumption Impacts]}$$

$$+\sum_{j=0}^{\infty} \beta^j \left(\frac{MCF_t - 1}{MCF_t}\right) \left[\frac{\partial G^T_{t+j}}{\partial T_{t+j}}\right] \left(\frac{U_{ct+j}}{U_{cct} C_t + U_{ct} + U_{lct} L_t - U_{cct} G^T_t (T_t)}\right) \frac{\partial T_{t+j}}{\partial E^M_t}$$

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\end{aligned}$$

Optimal Adaptation

Result 2 *Public adaptation to reduce direct utility losses should be less-than-fully provided (distorted) if governments raise revenues with distortionary taxes.*

Public adaptation to reduce climate impacts on final goods production and sea level rise capital losses should be undistorted (fully provided) regardless of the welfare costs of raising revenues.

- Intuition: Productivity benefits compensate for fiscal costs
- Optimal tax system maintains production efficiency (Diamond, Mirrlees, 1971); Provides public production inputs fully (Judd, 1999)

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Public Program Costs: Overview

- Synthesize prior estimates:
  - Hurricane-related public disaster spending: CBO (2016)
  - Wildfire suppression: U.S. Forest Service (2015), OMB (2016)
  - Crop insurance subsidies: U.S. Dept. of Agriculture (2016)
  - Air quality, health: Garcia-Menendez et al. (2015), OMB (2016)
  - West Nile Neuroinvasive Disease: EPA (2017)
  - Urban drainage infrastructure: EPA (2017)
- Own estimates: Wildfires and public healthcare
- Hybrid: Hurricanes and public healthcare, transfers; Deryugina (2017); Emmanuel et al. (2008); Bakkensen and Barrage (2019)

1) Synthesizing Prior Estimates:

Crop Insurance Cost Increase by 2080

	RCP 8.5	RCP 4.5	Source
Increase	+40%	+23%	OMB (2016)
Global Temp. Change (by 2075)	2.85 C	1.6 C	IPCC (2014)
Per 1 C impact:	+14.0%	+14.4%	

Wildfire Suppression Cost Increases

	RCP 8.5		Source
	2041-59	2081-99	
Global Temp. Change	2.0 C	3.7 C	IPCC (2014)
Forest Service	+117%	+192%	OMB (2016), USDA FS (2015)
Per 1 C impact:	+58.5%	+51.9%	
Dept. of Interior	+45%	+72%	OMB (2016), USDA FS (2015)
Per 1C impact:	+22.5%	+19.5%	

1) Synthesizing Prior Estimates:

Hurricane Relief Spending Increase by 2075		
	RCP 8.5	Source
Increase due to climate change	+14%	CBO (2016)
Global Temp. Change (by 2075)	2.85C	IPCC (2014)
Per 1C impact:	+5%	

West Nile Neuroinvasive Disease					
	RCP 8.5		RCP 4.5		Source
	2050	2090	2050	2090	
Global Temp. Change	2.0C	3.7C	1.4C	1.8C	IPCC (2014)
Additional Cases	720	2200	510	800	EPA (2017)
$\longrightarrow$ Federal costs ($ mil./yr)	$14.5	$45.1	$10.5	$16.4	EPA (2017), CMS (2020)
Regression coefficient per 1C:				+$10.5 mil/yr	

1) Synthesizing Prior Estimates:

Urban Drainage Infrastructure Costs (50-yr Storm)

	RCP 8.5		RCP 4.5		Source
	2050	2090	2050	2090	
Global Temp. Change	2.0C	3.7C	1.4C	1.8C	IPCC (2014)
Annual Cost ($2015 bil)	4.3	5.6	3.7	4.1	EPA (2017)
Per 1C impact:	2.2	1.5	2.6	2.3	
Regression coefficient per 1C				+$1.83 bil./yr	

Ambient Air Quality

		Source
	2100	
Global Temp. Change	6.0 C vs. 1.5C	Garcia-Menendez et al. (2015),OMB (2016)
Federal healthcare	+1.2 bil./yr	Garcia-Menendez et al. (2015),OMB (2016)
Per 1 C impact:	+267 $mil./yr	

2) Own Estimates: Wildfires and Public Healthcare

- Wildfires have been linked to poor air quality, increased healthcare utilization (e.g., Ahman et al. (2012) on 2012 Colorado fires; Gan et al. (2017) on Washington 2012 fires; Fan et al. (2018) national model)
  - Miller, Molitor, Zou et al. (2019): National data

- Data: County-year panel (1996-2018)
  - Top quartile of wildfire states (National Interagency Fire Center)

- Public medical transfers: BEA "Regional Economic Accounts" (REA); Centers for Medicare & Medicaid Services (CMMS)
- Wildfire and smoke events; other weather events: NOAA
- Air quality ratings: Environmental Protection Agency
- Demographics: REA, National Center for Health Statistics

Dep. Var.:	ln(Public Medical Expenditures)						
	Medicaid plus (Veterans etc.)			Medicare			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ln(Fire/SmokeDays)	0.0007**	0.0007**	0.0007**	0.0001	0.0006*	0.0001	0.0006*
	(0.0004)	(0.0004)	(0.0004)	(0.0002)	(0.0003)	(0.0002)	(0.0003)
ln(WinterEventDays)			0.0011***			0.0005**	0.0002
			(0.0004)			(0.0002)	(0.0003)
ln(RainThunderDays)			-0.0003			0.0004**	0.0002
			(0.0002)			(0.0002)	(0.0002)
ln(HeatEventDays)			0.0008*			0.0001	-0.0003
			(0.0004)			(0.0002)	(0.0002)
ln(ColdEventDays)			-0.0002			0.0001	0.0002
			(0.0004)			(0.0003)	(0.0003)
Obs.	15,289	15,289	15,289	15,302	15,302	15,302	15,302
Adj. R-Sq.	0.994	0.997	0.994	0.997	0.999	0.997	0.999
#Counties	701	701	701	701	701	701	701
Demo./Inc. Controls:	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pop. Weights:	No	Yes	No	No	Yes	No	Yes
County F.E.s:	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.s:	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-Trends:	Yes	Yes	Yes	Yes	Yes	Yes	Yes
S.E. Cluster	County	County	County	County	County	County	County

Details

2) Own Estimates: Wildfires and Public Healthcare

- Combine with projected wildfire increases by area:

Avg. Projected Change in Wildfire Activity* per 1 C global warming		
State	%Δ	Sources:
AZ	241	McKenzie et al. (2004), Littell et al. (2009), Liu et al. (2009)
UT	240	McKenzie et al. (2004), Littell et al. (2009), Liu et al. (2009)
NM	237	McKenzie et al. (2004), Littell et al. (2009), Liu et al. (2009)
NV	98	McKenzie et al. (2004), Littell et al. (2009), Liu et al. (2009)
ID	85	Littell et al. (2010), Liu et al. (2010)
CA	82	Lenihan et al. (2003), McKenzie et al. (2004), Littell et al. (2009)
OR	72	Rogers et al. (2011), Littell et al. (2010), Liu et al. (2010)
WA	72	Rogers et al. (2011), Littell et al. (2010), Liu et al. (2010)

*Acres burned per year or annual wildfire potential (Keetch-Byram Drought Index)

3) Hurricanes' Fiscal Costs

- Hurricane expenditure impacts: Deryugina (2017) data, code
- Climate-induced hurricane changes: Bakkensen and Barrage (2019) U.S. hurricane probability distribution estimates based on Emmanuel et al. (2008) synethtic cyclone tracks

Hurricane Impacts in Vulnerable Counties			
Saffir-Simpson Category:	Medical	Public Transfers	ΔE[U.S. Landfalls/yr] per $1^\circ C$
Cat. 1	3.7%	1.2%	+0.91
Cat. 2	3.6%	1.8%	+1.23
Cat. 3+	4.8%	6.76%	+2.04

Avg. *annual* per capita effect across estimated coefficients for years 0-10

→ Compute county-specific expenditure changes assuming equal spatial distribution of future U.S. hurricanes

Existing Program Costs: Summary

	$\%\Delta$ per $1^\circ C$	
Government Consumption	Program	Aggregate
Hurricane direct response	+5%	+0.04%
Crop-insurance subsidies	+14%	+0.04%
Wildfire suppression - FS	+52%	+0.04%
Wildfire suppression - DOI	+20%	+0.004%
Fed. healthcare - Air quality		+0.01%
Healthcare - Wildfires	varies by state	+0.008%
Healthcare - Hurricanes	varies by county	+0.19%
Urban drainage infrastructure		+0.03%
West Nile Neuroinvasive Disease		+0.0002%
Total		+0.38%
Government Transfers		
Income support - Hurricanes	varies by county	+0.11%

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Sea Level Rise: Impacts and Adaptation

- Quantify based on EPA Coastal Property Model (Neumann et al., 2014a,b) runs for 2018 National Climate Assessment (EPA, 2017)
- Damages: Storm surge impacts, abandoned property costs
- Adaptation: Shoreline armoring, beach nourishment, elevation

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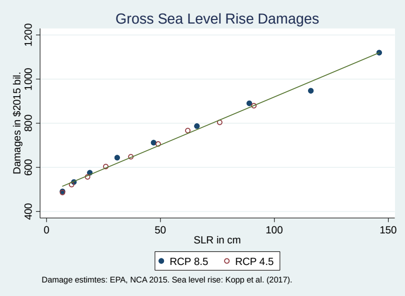
$$\delta(SLR_t, \Lambda_t^{slr}) = \overline{\delta} + (1 - \Lambda_t^{slr}) f(SLR_t)$$

- Set $f(SLR_t) = \delta^{SLR} K_t SLR_t$ based on 'no adaptation' scen.



Sea Level Rise: Impacts and Adaptation

- Adaptation capital AK_t and effectiveness Λ_t^{slr} :

$$AK_t \equiv \sum_{s=0}^{t-1} (\lambda_s^{slr} (1 - d^{slr})^s) + \lambda_s^{slr} \quad (1)$$

$$\Lambda_t^{SLR} = \left(\gamma_1 \frac{AK_t}{(\delta^{SLR} K_t SLR_t)} \right)^{\gamma_2} \quad (2)$$

- Use EPA model output as 'observations'

- Select d^{slr}, γ_1, γ_2 to minimize sum of squared errors between:
  - (1) and agg. damages with vs. without adaptation
  - Adaptation optimality condition $\frac{\partial \Lambda_t^{slr}}{\partial \lambda_t^{slr}} = \frac{1}{\delta^{SLR} K_t SLR_t}$

$\Rightarrow$ $d^{slr} = 0.246$ (annual depr. 2.8%), $\gamma_1 = 10.18$, $\gamma_2 = 0.09$

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COMET-US Calibration: Fiscal Baseline

Avg. Effective Tax Rate	Rate	Source
Capital (τ_{k0})	29.0%	CBO (2014)
Labor	30.9%	OECD (2018)
Consumption	6.1%	Carey and Tchilinguirian (2000)
$\longrightarrow$ Labor-Cons. Wedge (τ_{l0})	35.1%	

- Base $\overline{G_0^T}$, $\overline{G_0^C}$: U.S. National Income and Product Accounts
  - Grow at rates of population, technology growth
  - Plus climate impacts: $G_t^j(T_t) = \overline{G_t^j}(1 + \alpha_{j,1}(T_t))$, j=T,C
- Initial debt: 2015 federal debt held by domestic public (FRED)
  - Extension in progress: COVID update

COMET-US Calibration: Other Climate Impacts

- Structurally, output impacts as in RICE/DICE model family:

$$(1 - D(T_t)) = \frac{1}{1 + \alpha_y T_t^2}$$

- Quantitatively, disaggregate RICE U.S. damages into:

Production	Utility
70%	30%

-
  - Disaggregation procedure as in Barrage (2020a)
  - Also subtract SLR impacts to avoid double-counting

- $D(2.5^\circ C) \sim 0.62\%$ output loss
- $U(.) \sim$ Willing to pay 0.26% output to avoid $2.5^\circ C$ Details

COMET-US Calibration: Other

- Match base year (2015) output (BEA), labor supply (OECD), carbon energy (EPA)
- Population, productivity growth: RICE Model (Nordhaus, 2011)
- Abatement costs $\Theta(.)$: Match RICE per-ton costs (Nordhaus, 2011; Barrage, 2020)
- Carbon cycle, climate system: DICE (2010, 2016)
  - In progress: Update based on Dietz et al. (2020) (!)
- Preferences: CRRA, $\beta = (.985)^{10}$, $\sigma = 1.5$, Frisch labor supply elasticity 1.83 (Chetty et al., 2011)

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Fiscal Scenarios

- Income Taxes:

1. "First-Best": Gov't can levy non-distortionary lump-sum taxes
2. "Optimized Distortionary": Gov't can optimize (non-lump sum)
3. "Vary τ_l, BAU $\overline{\tau_k}$": Capital income taxes fixed at baseline ($\overline{\tau_k} = 29\%$), gov't can raise labor income taxes
4. "BAU $\overline{\tau_l}$, Vary τ_k": Labor income taxes fixed at baseline ($\overline{\tau_l} = 35.1\%$), gov't can raise capital income taxes

- Carbon & Energy Taxes:

1. "No": Business-as-usual, no carbon/energy taxes until 2115
2. Otherwise: Optimized

Main Results: Benchmark

Scenario Income	Scenario Carbon & Energy	Labor Tax	Capital Tax	MCF	Carbon Tax ($/mtC)	ΔWelfare EV ΔC_{2015} ($2015 bil.)
		Avg. 2025-2215			2015-25	
First-Best	No	0	0	1.00	0	
First-Best	Opt.	0	0	1.00	11.1	127

ROW Emissions: BAU

Main Results: Benchmark

Scenario: Income	Scenario: Carbon & Energy	Labor Tax (Avg. 2025-2215)	Capital Tax (Avg. 2025-2215)	MCF (Avg. 2025-2215)	Carbon Tax ($/mtC) (2015-25)	ΔWelfare EV ΔC_{2015} ($2015 bil.)
First-Best	No	0	0	1.00	0	
First-Best	Opt.	0	0	1.00	11.1	127
Opt.	No	40.3	4.6	1.10	0	
Opt.	Opt.	40.2	4.7	1.10	8.7	155

ROW Emissions: BAU

Main Results: Benchmark

Scenario: Income	Scenario: Carbon & Energy	Labor Tax	Capital Tax	MCF	Carbon Tax ($/mtC)	ΔWelfare EV ΔC_{2015} ($2015 bil.)
		Avg. 2025-2215			2015-25	
First-Best	No	0	0	1.00	0	
First-Best	Opt.	0	0	1.00	11.1	127
Opt.	No	40.3	4.6	1.10	0	
Opt.	Opt.	40.2	4.7	1.10	8.7	155
BAU $\overline{\tau_l}$,	No	$\overline{35.1}$	35.2	1.54	0	
vary τ_k	Opt.	$\overline{35.1}$	33.8	1.51	7.1	635

ROW Emissions: BAU

Main Results: Benchmark

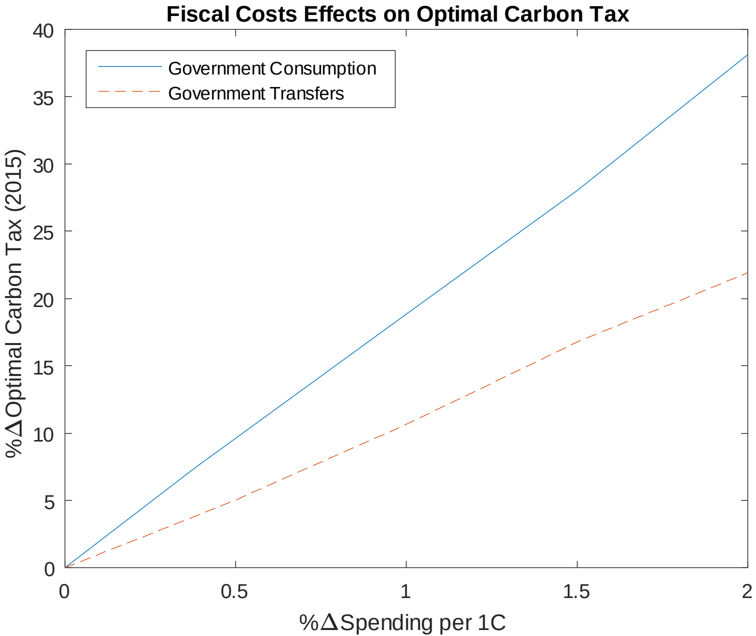
Scenario: Income	Scenario: Carbon & Energy	Labor Tax (Avg. 2025-2215)	Capital Tax (Avg. 2025-2215)	MCF (Avg. 2025-2215)	Carbon Tax ($/mtC) (2015-25)	ΔWelfare EV ΔC_{2015} ($2015 bil.)
First-Best	No	0	0	1.00	0	
First-Best	Opt.	0	0	1.00	11.1	127
Opt.	No	40.3	4.6	1.10	0	
Opt.	Opt.	40.2	4.7	1.10	8.7	155
BAU $\overline{\tau_l}$, vary τ_k	No	$\overline{35.1}$	35.2	1.54	0	
BAU $\overline{\tau_l}$, vary τ_k	Opt.	$\overline{35.1}$	33.8	1.51	7.1	635
BAU $\overline{\tau_k}$, vary τ_l	No	39.6	$\overline{29.0}$	1.10	0	
BAU $\overline{\tau_k}$, vary τ_l	Opt.	39.5	$\overline{29.0}$	1.10	8.4	144

ROW Emissions: BAU

ROW Opt.

Main Results: ROW Emissions Response Elasticity 0.5

Scenario: Income	Scenario: Carbon & Energy	Labor Tax (Avg. 2025-2215)	Capital Tax (Avg. 2025-2215)	MCF (Avg. 2025-2215)	Carbon Tax ($/mtC) 2015-25	ΔWelfare EV ΔC_{2015} ($2015 bil.)
First-Best	No	0	0	1.00	0	
First-Best	Opt.	0	0	1.00	46.1	502
Opt.	No	40.3	5.0	1.10	0	
Opt.	Opt.	40.2	5.0	1.10	40.1	651
BAU $\overline{\tau_l}$,	No	$\overline{35.1}$	35.3	1.54	0	
vary τ_k	Opt.	$\overline{35.1}$	33.7	1.50	35.8	1,216
BAU $\overline{\tau_k}$,	No	39.6	$\overline{29.0}$	1.09	0	
vary τ_l	Opt.	39.5	$\overline{29.0}$	1.09	39.8	612



Fiscal Costs Effects on Optimal Carbon Tax
Government Consumption
Government Transfers
%ΔOptimal Carbon Tax (2015)
%ΔSpending per 1C
0
5
10
15
20
25
30
35
40
0.5
1
1.5
2

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Conclusion

- Consideration of fiscal setting and climate impacts:
- Changes optimal carbon price to account for:
  - Gov't consumption impacts [$+19\%$ per $1\%\Delta G_t^C/^\circ C$]
  - Gov't transfer impacts if $MCF > 1$ [$+10\%$ per $1\%\Delta G_t^T/^\circ C$]
- New bottom-up U.S. fiscal damage functions
  - Currently: Gov't consumption $+0.38\%$ per $1^\circ C$
  - Currently: Gov't transfers $+0.11\%$ per $1^\circ C$
- May significantly increase welfare gains from carbon pricing
  - +10-400% with distortionary vs. lump-sum taxes
  - *Failure* to price carbon requires other tax increases
- Many caveats! But results highlight *potential importance* of fiscal effects $\Rightarrow$ Warrant further empirical, IAM consideration

Main Results: ROW Optimal

Scenario: Income	Scenario: Carbon & Energy	Labor Tax	Capital Tax	MCF	Carbon Tax ($/mtC)	ΔWelfare EV ΔC_{2015} ($2015 bil.)
		Avg. 2025-2215			2015-25	
First-Best	Opt.	0	0	1.00	11.1	154
First-Best	No	0	0	1.00	0	
Opt.	Opt.	40.1	5.2	1.10	8.6	177
Opt.	No	40.1	5.9	1.10	0	
BAU $\overline{\tau_l}$, vary τ_k	Opt.	$\overline{35.1}$	32.7	1.47	7.2	604
	No	$\overline{35.1}$	34.0	1.50	0	
BAU $\overline{\tau_k}$, vary τ_l	Opt.	39.4	$\overline{29.0}$	1.09	8.3	170
	No	39.6	$\overline{29.0}$	1.09	0	

ROW Emissions: Global Optimum (RICE)

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COMET-US Calibration: Preferences

- Dynastisc household lifetime utility:

$$\sum_{t=0}^{\infty} \beta^t N_t U(c_t, l_t, T_t)$$

$$U(c_t, l_t, T_t) = \frac{\left[c_t \cdot (1 - \varsigma l_t)^{\gamma}\right]^{1-\sigma}}{1-\sigma} + \frac{\left(1 + \alpha_u T_t^2\right)^{-(1-\sigma)}}{1-\sigma}$$

- With $\beta = (.985)^{10}$, $\sigma = 1.5$
- ς, γ set to match (i) base year labor supply (OECD), (ii) Frisch elasticity of labor supply 1.83 (Chetty et al., 2011)
- α_u set to match willingness-to-pay to avoid $2.5^{\circ}C$ equal to 0.26 pct. of output in 2065

Back

2) Wildfires and Public Healthcare: Specification

$$\ln Y_{j,t} = \gamma_j + \delta_t + (\theta_s \cdot t) + \beta_1 \ln \text{Fire/SmokeDays}_{j,t} + \mathbf{X_{j,t}}'\boldsymbol{\beta} + \epsilon_{j,t}$$

- $\ln Y_{j,t} \sim$ ln p.c. public medical spending, $\gamma_j \sim$ county fixed effects, $\delta_t \sim$ year fixed effects, $(\theta_s \cdot t) \sim$ state-specific trend
- $\text{lnFireDays}_{j,t} \sim$ num. fire or smoke days in county-year
- $\mathbf{X_{j,t}} \sim$ ln of pop., pop$>$65, inc. p.c.; pop. growth, inc. growth, pct. non-hisp. white; other weather days
  - "Medicare Controls": Medicare beneficiares: ln. num, pct. female, pct. non-hisp. white, pct. Medicare Advantage, avg. age; county avg. Hierarchical Condition Category score

- Alternative: 2SLS isolating link from FireDays to number of days with "unhealthy" air (EPA) in county-year

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Dep. Var.:	ln(Public Medical Expenditures)						
	Medicaid plus (Veterans etc.)			Medicare			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ln(FireDays)	0.0007**	0.0007**	0.0007**	0.0001	0.0006*	0.0001	0.0006*
	(0.0004)	(0.0004)	(0.0004)	(0.0002)	(0.0003)	(0.0002)	(0.0003)
ln(WinterEventDays)			0.0011***			0.0005**	0.0002
			(0.0004)			(0.0002)	(0.0003)
ln(RainThunderDays)			-0.0003			0.0004**	0.0002
			(0.0002)			(0.0002)	(0.0002)
ln(HeatEventDays)			0.0008*			0.0001	-0.0003
			(0.0004)			(0.0002)	(0.0002)
ln(ColdEventDays)			-0.0002			0.0001	0.0002
			(0.0004)			(0.0003)	(0.0003)
Obs.	15,289	15,289	15,289	15,302	15,302	15,302	15,302
Adj. R-Sq.	0.994	0.997	0.994	0.997	0.999	0.997	0.999
#Counties	701	701	701	701	701	701	701
Demo./Inc. Controls:	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pop. Weights:	No	Yes	No	No	Yes	No	Yes
County F.E.s:	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.s:	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-Trends:	Yes	Yes	Yes	Yes	Yes	Yes	Yes
S.E. Cluster	County	County	County	County	County	County	County

	(1)	(2)	(3)	(4)
	First Stage	Second Stage	First Stage	Second Stage
	ln(Unhealthy Days)	ln(Public Medical Expend.)	ln(Unhealthy Days)	ln(Emergency Dep. Visits/ 1000 Ben.)
ln(FireDays)	0.0728***		0.0798***	
	(0.0166)		(0.0222)	
ln(UnhealthyDays)		0.0082**		0.0069*
		(0.0033)		(0.0041)
Obs.	4,704	4,704	2,320	2,320
#Counties	282	282	237	237
Demo./Inc. Controls:	Yes	Yes	Yes	Yes
Medicare Controls:	-	-	Yes	Yes
County F.E.s:	Yes	Yes	Yes	Yes
Year F.E.s:	Yes	Yes	Yes	Yes
State-Trends:	Yes	Yes	Yes	Yes
S.E. Cluster	County	County	County	County
Adj. R-Sq.		0.973		0.203
Kleibergen-Paap Wald F. Stat.	19.3		12.98	

	(1)	(2)
	First Stage	Second Stage
	ln(Unhealthy Days)	ln(Outp. Dialysis Events/1000 Ben.)
ln(FireDays)	0.0761***	
	(0.0222)	
ln(UnhealthyDays)		-0.0020
		(0.0057)
Obs.	2,298	2,298
#Counties	233	233
Demo./Inc. Controls:	Yes	Yes
Medicare Controls:	Yes	Yes
County F.E.s:	Yes	Yes
Year F.E.s:	Yes	Yes
State-Trends:	Yes	Yes
S.E. Cluster	County	County
Adj. R-Sq.		0.558
Kleibergen-Paap Wald F. Stat.	11.70	