

Carbon prices, preferences, and the timing of uncertainty



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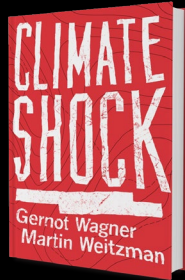
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\$40

>>\$40, two (of many) ways:

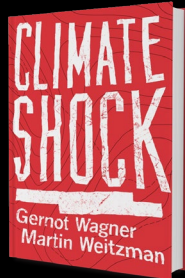
1 Tail risk



2 Epstein-Zin preferences

>>\$40, two (of many) ways:

1 Tail risk



2 Epstein-Zin preferences



Two critical examinations:

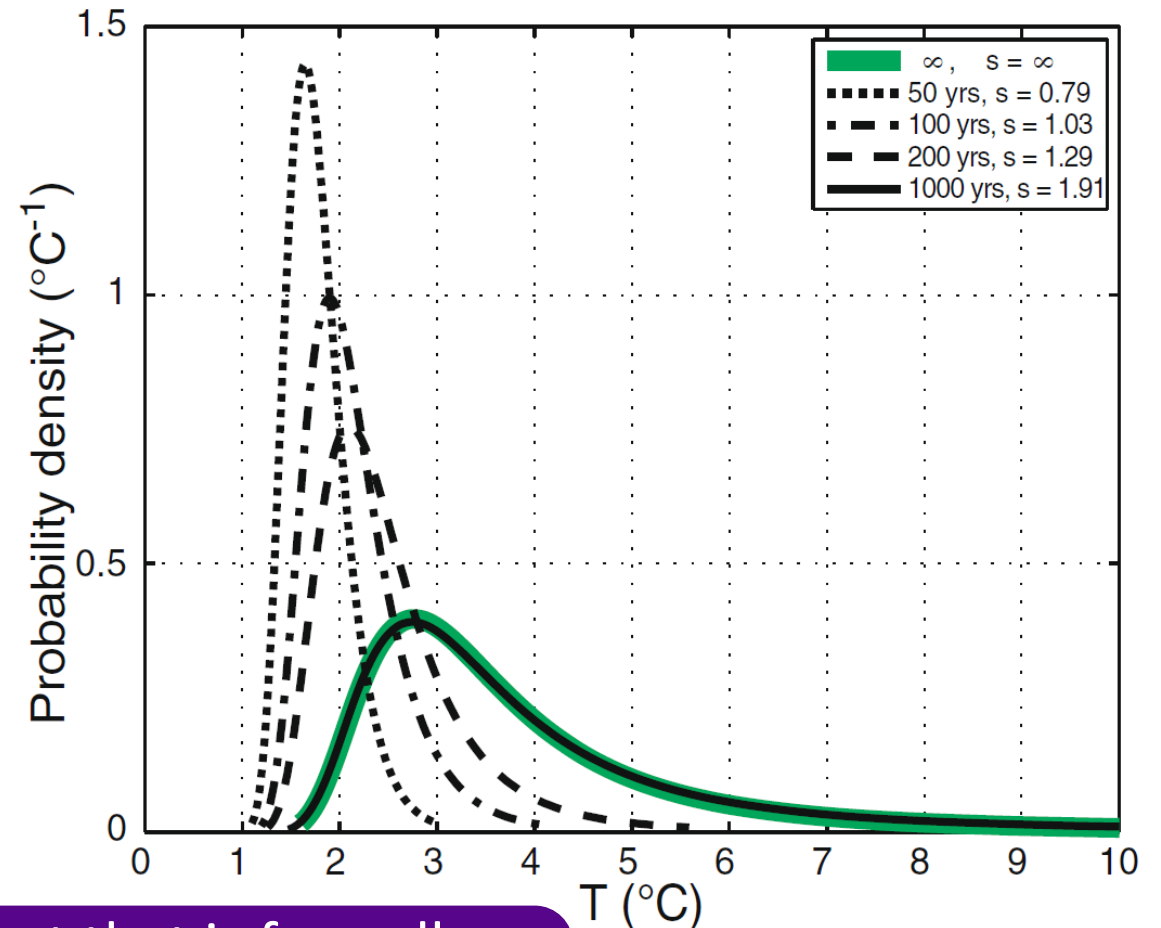
- 1 “Roe-Bauman” time component
- 2 Closer look at discounting

1

Roe-Bauman critique of “fat tails” argument

“Climate sensitivity: should the climate tail wag the policy dog?”

“**Fig. 2 b** The shape of the [climate sensitivity] distribution at particular times. The skewness of the distributions are also shown in the legend; as described in the text, **the upper bound on possible temperatures is finite at finite time, limiting the skewness**” (Roe & Bauman, 2013, p. 651)



“even for a planet that is formally headed to[ward] oblivion, it can take a very long time to get there”

Carbon prices, preferences, and the timing of uncertainty

3 questions

1

Does the Roe-Bauman (RB) critique matter?

2

Does the separation of risk and time *a la* Epstein-Zin (EZ) matter?

1

&

2

What about the combination of the two?

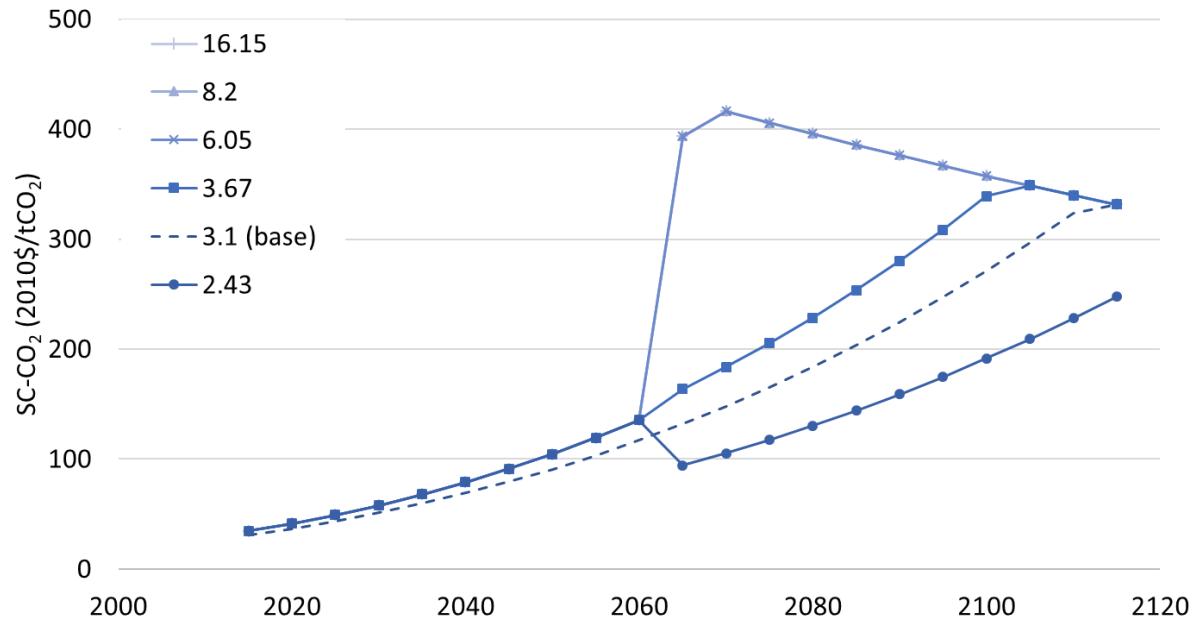
We build “DICE-EZ-RB” to help answer these questions

1

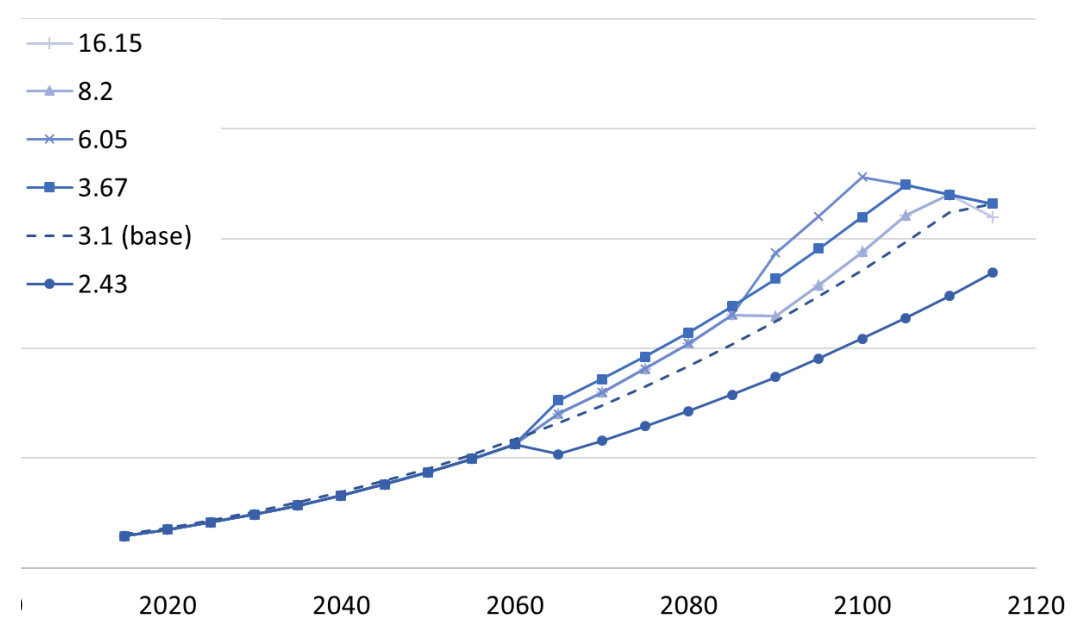
Roe-Bauman time dynamics dramatically reduce SC-CO₂ uncertainty

SC-CO₂ smaller in expectations, less uncertain after resolution of uncertainty

DICE with Roe-Baker tail uncertainty



DICE with Roe-Bauman time dynamics



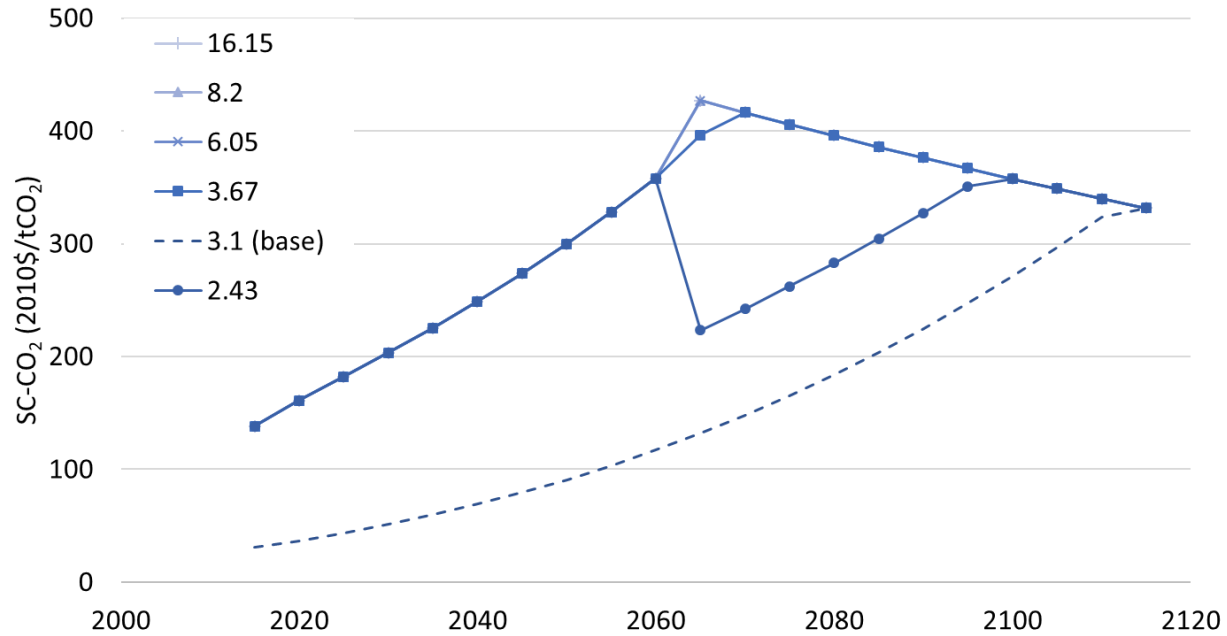
Tail risks much less significant, given time interaction (discounting!)

1 & 2

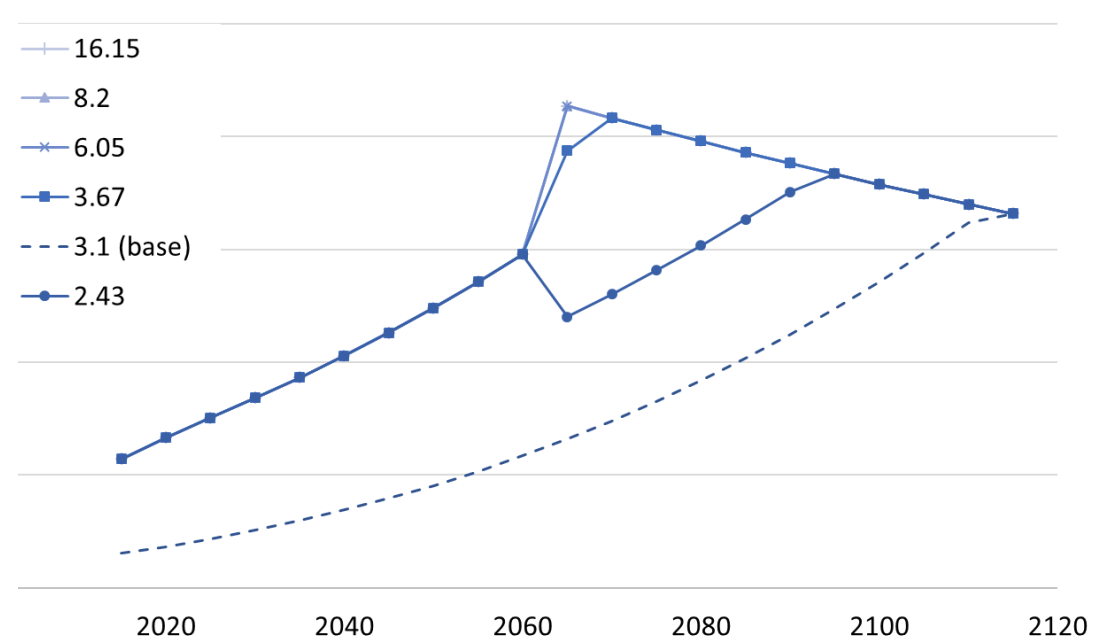
Impact of EZ preferences much larger than RB dynamics

Initial SC-CO₂ jumps to over \$100

DICE-EZ



DICE-EZ-RB



Switch to EZ appears to have large impact on SC-CO₂

1

2

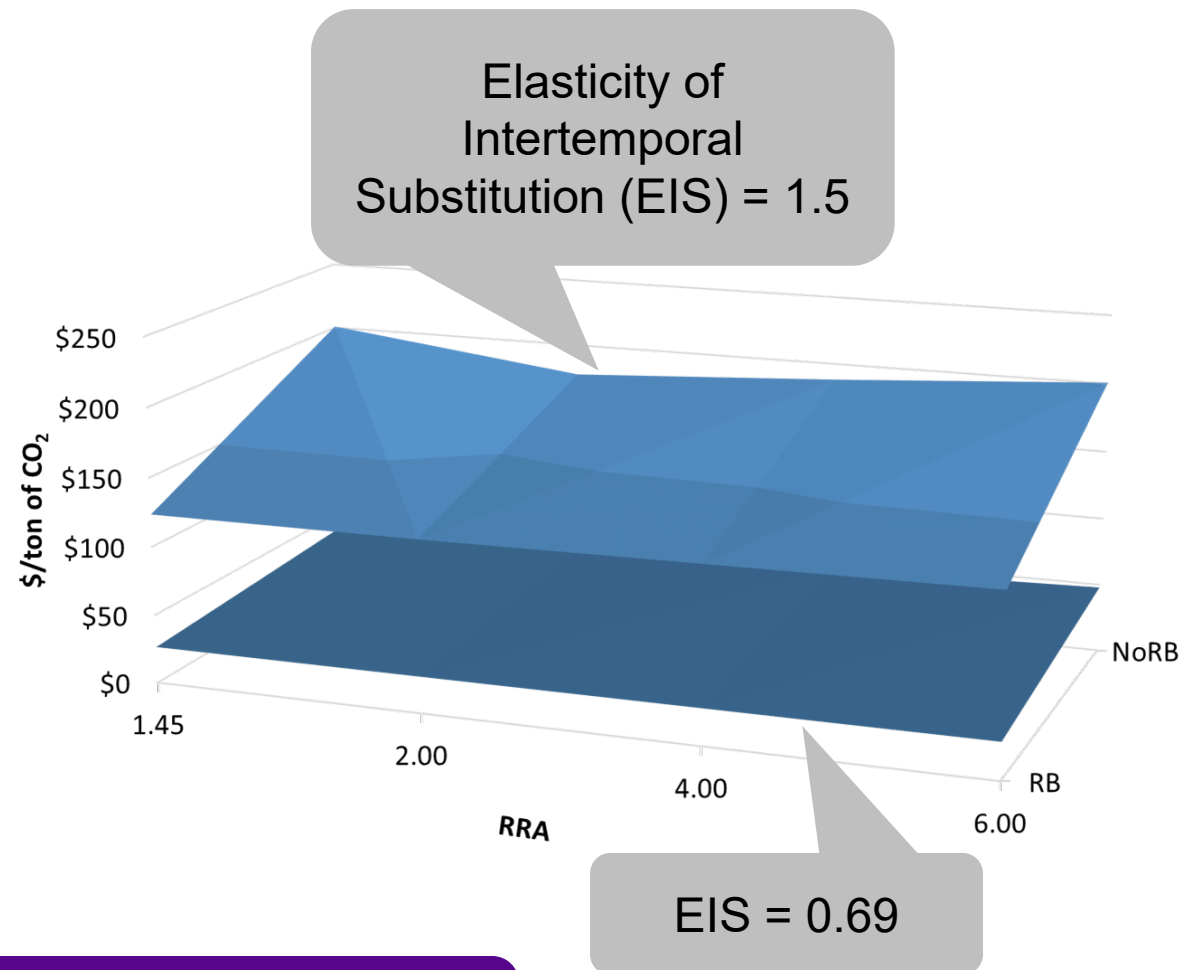
Roe-Bauman (RB) time-delay decreases SCC by >30%

DICE calibration (EIS = 0.69 and RRA = 1.45) changes from \$31

DICE calibration
(SCC = \$31)

	EIS = 0.69			
	RRA = 1.45	2	4	6
RB	\$ 26	\$ 26	\$ 27	\$ 27
no RB	\$ 38	\$ 39	\$ 43	\$ 48

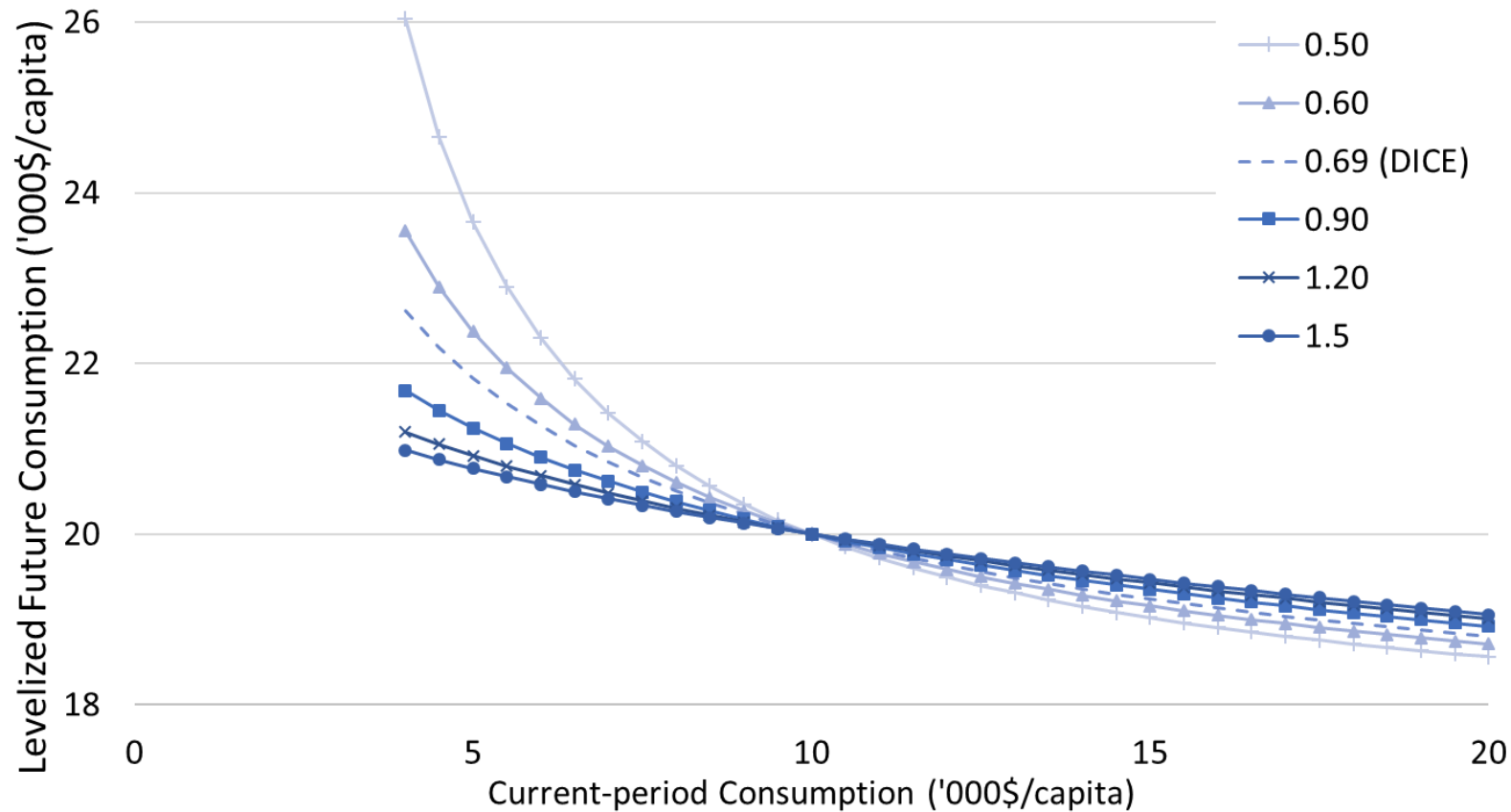
	EIS = 1.5			
	RRA = 1.45	2	4	6
RB	\$ 123	\$ 124	\$ 126	\$ 128
no RB	\$ 201	\$ 177	\$ 188	\$ 201



Impact of changes to EIS (far) greater than RB/noRB and RRA?

Elasticity of Intertemporal Substitution (EIS) drives all

SC-CO₂ very sensitive to EIS parameters; EIS meanwhile, anywhere from ~0.50 to >1.5 (Thimme 2017)



What's the right EIS? aka
There appears to be no escaping
economics' philosophical roots.

1. Time matters
2. Time matters in 2 ways: race between tails and discounting (the Roe-Bauman critique, “RB”) and move to Epstein-Zin preferences (“EZ”)
3. Choice of Elasticity of Intertemporal Substitution (EIS) for EZ preferences matters (much) more than RB time-delay
4. There appears to be no escaping economics’ philosophical roots.



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4. There appears to be no escaping economics’ philosophical roots.

Declining CO₂ price paths

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Pricing greenhouse-gas (GHG) emissions involves making trade-offs between consumption today and unknown damages in the distant future. While decision-making under risk and uncertainty is the forte of financial economics, important insights from pricing financial assets do not typically inform standard climate-economy models. Here we introduce EZ-Climate, a simple recursive dynamic asset pricing model that allows for a realistic calibration of the carbon dioxide (CO₂) price path based on probabilistic assumptions around climate damages. Atmospheric CO₂ is the ‘asset’ with a negative expected return. Here economic model focuses on society’s willingness to substitute damages for risk from intertemporal substitution. In contrast to most modeled CO₂ price paths, EZ-Climate suggests a high price today that is expected to decline over time as the insurance-value of mitigation declines and technological change makes emissions cuts cheaper. Second, higher risk aversion increases both the CO₂ price and the risk premium relative to expected damages. Lastly, our model suggests large costs associated with delays in pricing CO₂ emissions. In our base case, delaying implementation by one year leads to annual consumption losses of over 2%, a cost that roughly increases with the square of time per additional year of delay. EZ-Climate also makes clear how sensitive results are to key inputs.

For over 25 years, the dynamic integrated climate-economy (DICE) model (1–3) has been the standard tool for analyzing CO₂ emissions pathways, and for good reason. One attraction is its simplicity, turning a “market failure on the greatest scale the world has seen” (4) and “the mother of all externalities” (5) into a model with fewer than 20 main equations (7). It has also helped set the tone for “optimal” CO₂ price paths, and for climate policy more broadly. The core trade-off between economic consumption and climate damages leads to relatively low CO₂ prices today rising over time. DICE and models like it have well-known limitations, including how they represent climate risk and uncertainty (7–15). Those limitations extend to the fundamental framework used in translating climate projections into monetary damages: DICE, economists employing modern dynamic analysis, even though it leads itself to these extensions (9–12). The underlying structure all-but prescribes a rising CO₂ price path over time. One important limitation is the form of the utility function. Constant relative risk aversion (CRRA) preferences, standard in most climate-economy models (1, 7, 16), assume that economic agents have an equal aversion to variation in consumption across states of nature and over time. Evidence from financial markets suggests this is not the case (17). The risk premium of equities over bonds points to a fundamental difference in how much society is willing to pay to substitute climate risk | asset pricing | cost of carbon

$$U_t = [(1 - \beta) e^{\rho t} + \beta (E_t [U_{t+1}^{\alpha}])^{\frac{1}{\alpha}}]^{\alpha} \quad [1]$$

Significance Statement
Risk and uncertainty are important in pricing climate damages. Despite a burgeoning literature, attempts to marry insights from asset pricing with climate economics have largely failed to supplement—let alone supplant—decades-old climate-economy models, largely due to their analytic and computational complexity. Here we introduce a simple, modular framework that identifies core trade-offs, highlights the sensitivity of results to key inputs, and helps pinpoint areas for further work.

The authors declare no conflict of interest.
¹K.D., R.B.L., and G.W. contributed equally to this work.
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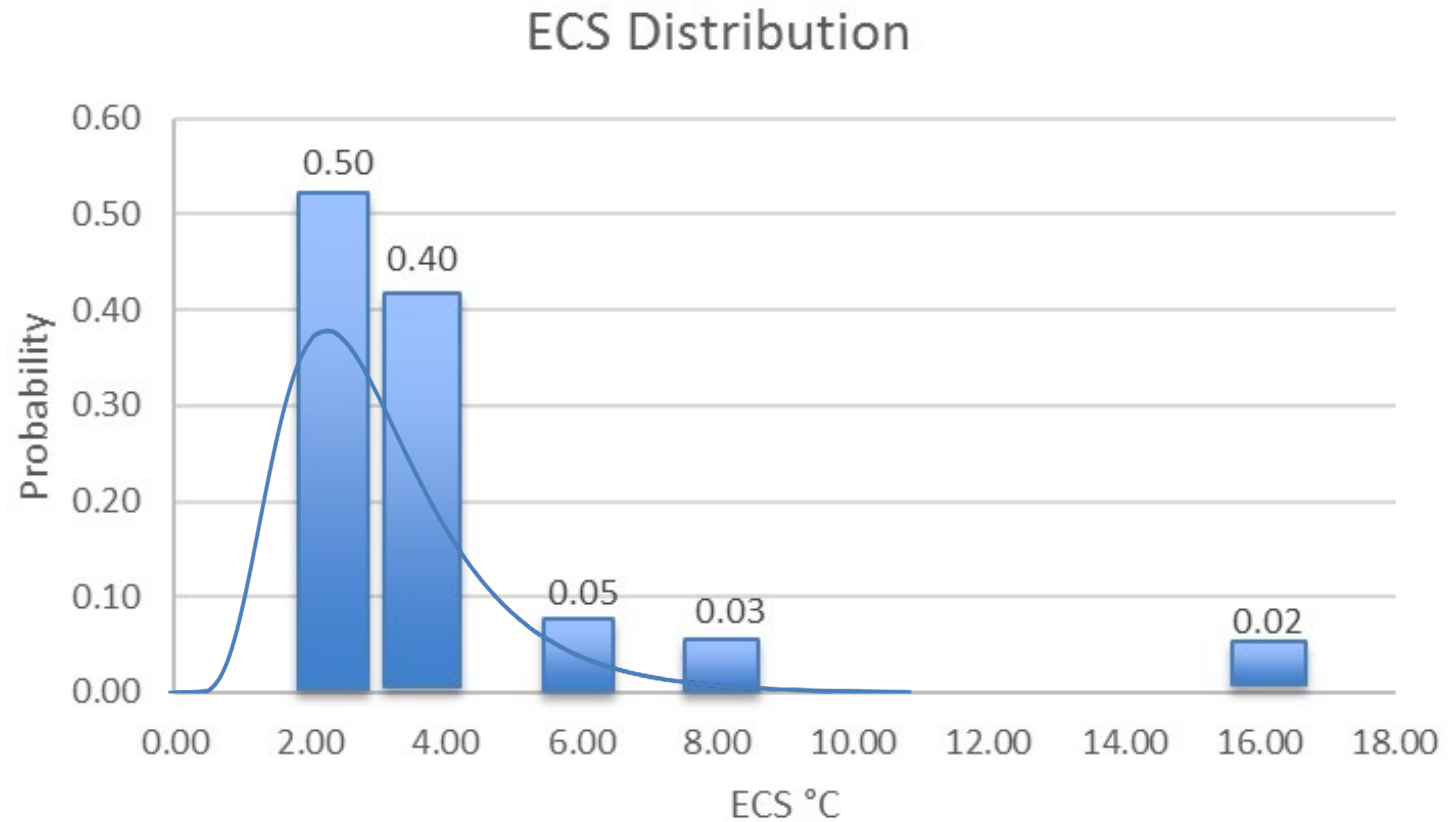


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Backup

1 *Rough* Roe-Baker ECS calibration

Recursive DICE-EZ implementation calls for simple scenarios: 5 scenarios, with ECS uncertainty resolved in 50yrs (2065)

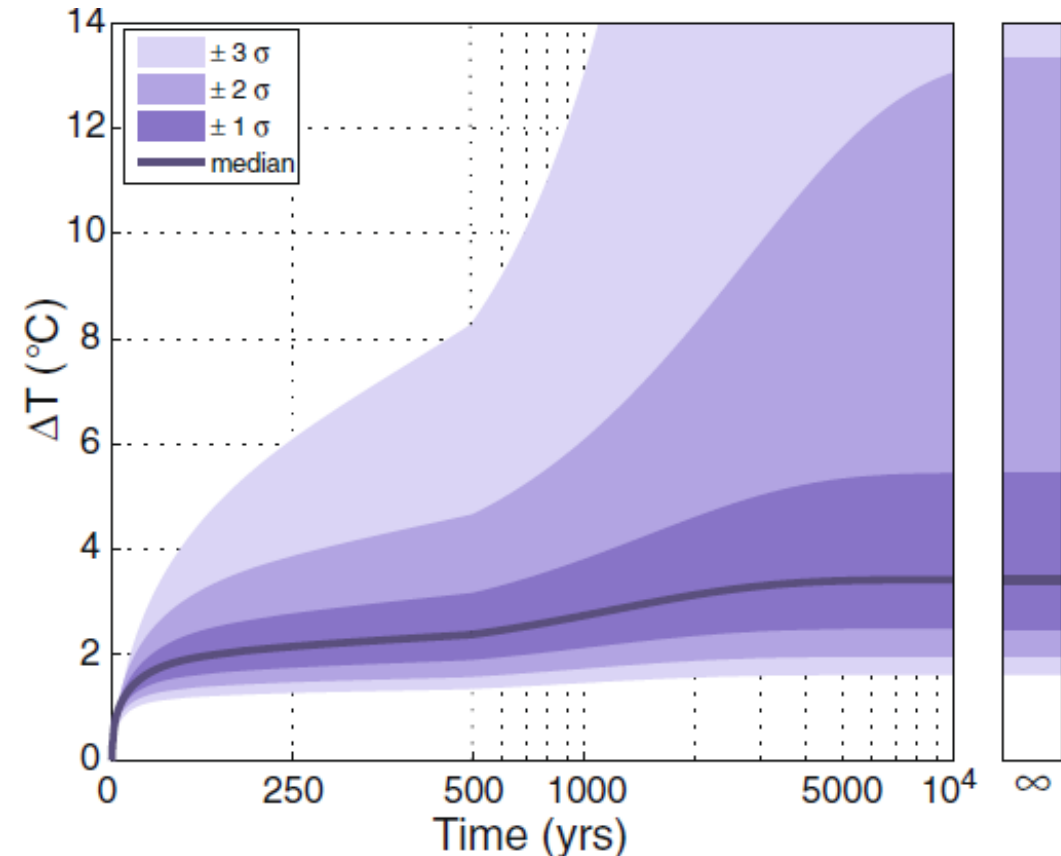


1

Roe-Bauman critique of “fat tails” argument

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Fig. 2 a The time evolution of uncertainty in global temperature in response to an instantaneous doubling of CO₂ at t = 0, and for standard parameters. The shading reflects the range of feedbacks considered (symmetric in feedbacks, but not in climate response), as explained in the text. Note the change to a logarithmic x-axis after t = 500 yr. The panel illustrates that **for high climate sensitivity it takes a very long time to come to equilibrium.**” (Roe & Bauman, 2013, p. 651)



The farther out the climate damage,
the more discounting matters

“DICE-EZ-RB” based on DICE with modified utility & calibration (1/2)

Based on Ackerman *et al.* (2013) and Roe & Bauman (2013), and Nordhaus (2013, 2016)

Epstein-Zin utility:

$$U_t = \left[(1 - \beta) c_t^\rho + \beta \left(\mu_t [U_{t+1}]^\rho \right) \right]^{\frac{1}{\rho}}$$

$$\mu_t [U_{t+1}] = \left(E_t [U_{t+1}^\alpha] \right)^{\frac{1}{\alpha}}$$

modified to allow for intra-period uncertainty in consumption:

$$U_t = \left[(1 - \beta) \mu_t (c_t)^\rho + \beta \left(\mu_t [U_{t+1}]^\rho \right) \right]^{\frac{1}{\rho}}$$

$$\mu_t [U_{t+1}] = \left(E_t [U_{t+1}^\alpha] \right)^{\frac{1}{\alpha}}$$

$$\mu_t [c_t] = \left(E_t [c_t^\alpha] \right)^{\frac{1}{\alpha}}$$

Utility of c_t is uncertain in each period,
not just in its present value

“DICE-EZ-RB” based on DICE with modified utility & calibration (2/2)

Based on Ackerman *et al.* (2013) and Roe & Bauman (2013), and Nordhaus (2013, 2016)

Modify temperature pathway from “ ΔT_{DICE} ” to “ $\Delta T'$ ” in:

$$T_{AT}(t) = T_{AT}(t-1) + \xi_1 \left\{ F(t) - \xi_2 T_{AT}(t-1) - \xi_3 [T_{AT}(t-1) - T_{LO}(t-1)] \right\}$$

$$T_{LO}(t) = T_{LO}(t-1) + \xi_4 [T_{AT}(t-1) - T_{LO}(t-1)].$$

by scaling parameters, e.g.:

$$\xi'_2 = \xi_2 \left(\frac{\Delta T'}{\Delta T_{DICE}} \right)^{-1} \quad \xi'_3 = \xi_3 \left(\frac{\Delta T'}{\Delta T_{DICE}} \right)^{\lambda_{RB}}$$

We instead scale based on fraction of asymptotic adjustment; i.e. time it takes to get to $1 - 1/e$, or $\sim 63\%$.

→ Choose parameters ξ'_1, ξ'_3, ξ'_4 to minimize squared deviation from DICE parameters:

$$\frac{T(ECS, p)}{T(3.1, p)} = \left(\frac{y}{3.1} \right)^2$$

Why care about distribution of climate damages?

Informs optimal stringency of GHG-mitigation policy, possible targeting of adaptation policy.

- **Mitigation:**

- diminishing marginal utility of consumption and/or equity weighting affects SCC estimates¹
- e.g. DICE assumes representative agent, proportional damages; likely biased down if damages regressive in reality

¹For instance, see Anthoff et al. (2009) and Anthoff and Emmerling (2019)

²For instance, in the case of wildfire risk (Baylis and Boomhower, 2018) or flood protection (Barrage and Furst, 2019).

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- **Adaptation:**

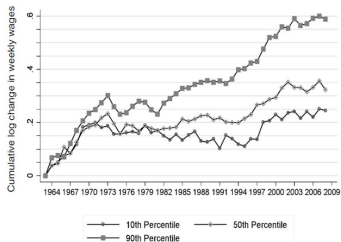
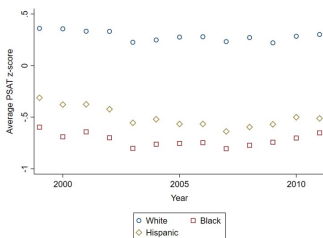
- implicit or explicit adaptation policies may be progressive or regressive²
- understanding sources of heterogeneity (e.g. credit constraints, health capital, built env.) may help target interventions

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Why care about distribution of climate damages?

Understanding determinants of economic inequality more broadly



- **Educational achievement gaps:**
 - Large and persistent racial achievement gaps: relatively little research on contribution of physical environment³
- **Polarization of labor market:**
 - Rising wage-inequality and returns to schooling, in part due to skill-biased technical change: effect of climate unclear⁴

³ Jencks and Phillips (2011), Fryer Jr (2017), Hanushek and Woessmann (2016), Reardon et al. (2017)

⁴ Autor et al. (2003); Goldin and Katz (2009); Acemoglu and Restrepo (2017)

What do we know about dist. of climate damages?

Cross-country evidence:

- Dell et al. (2012), Burke et al. (2015), Diffenbaugh and Burke (2019) suggest temperature-GDP/growth relationship larger for poorer countries
- Carleton et al. (2018) suggest similar temperature-mortality β differences globally

Important work of micro-founding macro-damage functions ongoing (Metcalf and Stock, 2017)⁵

Within-country evidence more limited⁶

⁵ See Dell et al. (2014), Heal and Park (2016), Hsiang et al. (2018) for reviews.

⁶ Notable exceptions include Hsiang et al. (2017), Heilmann and Kahn (2019).

Ongoing research: Temperature and Labor/Human capital

Research objectives

- Explore whether and how climatic factors (extreme temp) affect economic opportunity - focusing on labor and human capital outcomes
- Better understand the role of adaptation investments
- Explore potential implications for distributional equity and policy design

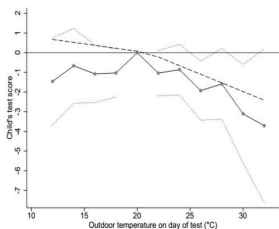
Heat and Human Capital

- Park (2017)
- Park, Goodman, Hurwitz, Smith (forthcoming, AEJ:EP)
- Park, Behrer, Goodman (ongoing)

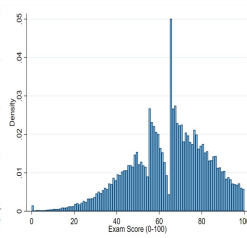
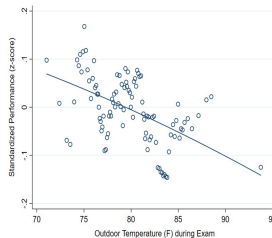
Heat and Labor

- Behrer, Pankratz, Park (ongoing)
- Park and Stainier (ongoing)

Temperature and Cognitive Performance



Graff-Zivin, Neidell, Hsiang (2017)

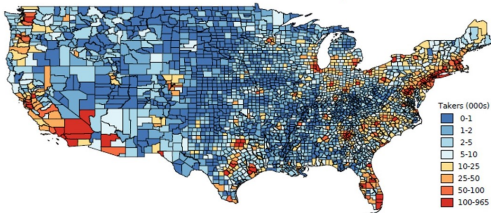


Park (2017)

- Exam on 90°F day → -13% of sd, affects graduation probability
- Short-run cognitive performance \neq long-run human capital accumulation

Heat and Learning

22 million student-level PSAT records, 1997-2012



Survey of school air conditioning, 12,000 schools

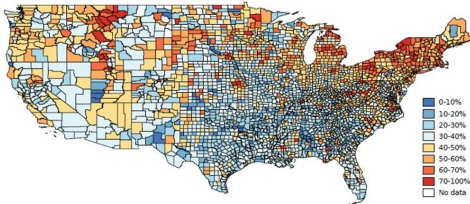


Figure: Park, Goodman, Hurwitz, Smith (forthcoming, AEJ: EP)

Heat and Learning

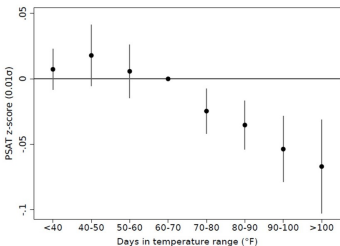
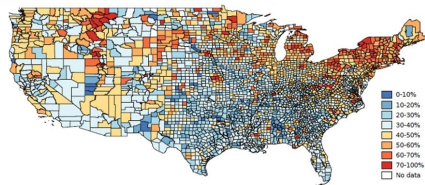
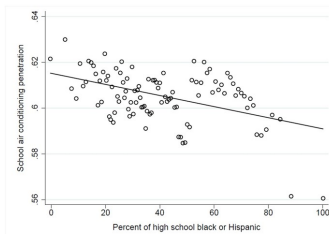


Table 3: Timing of Temperature Shocks

	(1)	(2)	(3)	(4)	(5)
(B) Days above 90 °F					
School days, 1 year prior	-0.056*** (0.012)	-0.061*** (0.011)	-0.073*** (0.016)		-0.078*** (0.014)
Summer days, 1 year prior		0.016 (0.011)		0.018 (0.011)	
Weekend days, 1 year prior			0.043 (0.028)		
School days, post-summer				-0.074*** (0.019)	
School days, pre-summer				-0.074*** (0.016)	
School days, 2 years prior					-0.051*** (0.013)
School days, 3 years prior					-0.048*** (0.014)
N	21,046,448	21,046,448	21,046,448	21,046,448	21,046,448

- +1°F → -1% of annual learning gains; -2 to -3% for B/H students
- Effect driven entirely by hot school days: weekdays in school year

Heat and Learning



Estimated percent of classrooms without AC (2017)

	Black/ Hispanic (1)	White (2)	High minority HS (3)	Low minority HS (4)	Low income ZIP code (5)	High income ZIP code (6)
Days above 90 °F	-0.072*** (0.015)	-0.027*** (0.008)	-0.072*** (0.017)	0.003 (0.014)	-0.076*** (0.016)	-0.031** (0.013)
N	6,023,145	12,161,058	4,129,153	4,239,916	4,531,817	4,107,140

- School AC highly correlated with income and race, avg climate
- Hotter average climate + lower levels of AC → ≈ 5% to 7% of racial achievement gap

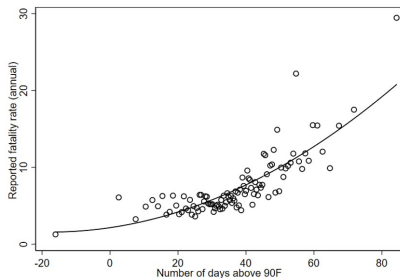
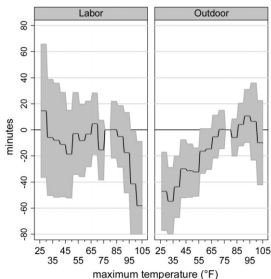
Heat and Labor



Many workers experience routine temperature exposure on the job

- 1.1b agricultural, 180m construction, 70m textile workers globally
- Over 30m US workers employed in "highly exposed" sectors

Heat and Labor



Heat appears to reduce labor supply, manufacturing productivity⁷

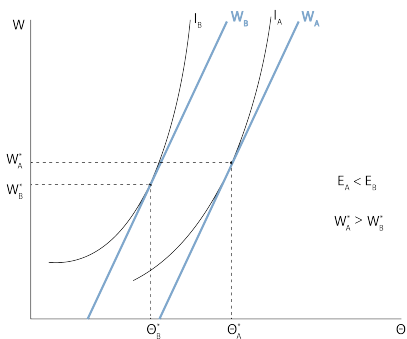
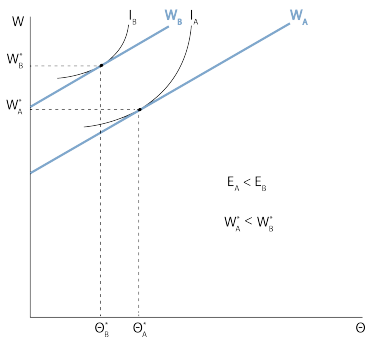
Ongoing work (with Behrer and Pankratz):

- confidential micro-data on injuries: CFOI/SOII; OSHA; CA DWC (n=17m, 2000-2017)
- preliminary results: addtl 90°F day → +3% weekly injury risk

⁷ Graff Zivin and Neidell (2014), Cachon et al. (2012), Somanathan et al. (2018).

Heat and Labor: Compensating Differentials

Heterogeneous workers (skill) and firms (adaptation costs). Matching equilibrium (Rosen, 1974; Hamermesh, 1998)



Compensating differentials and income effects mean sign of θ -wage relationship is theoretically ambiguous in cross-section

Heat and Labor: Compensating Differentials

Ongoing work: BLS, ONET, BEA data on average wages, schooling/skill requirements, geographic employment distribution by year

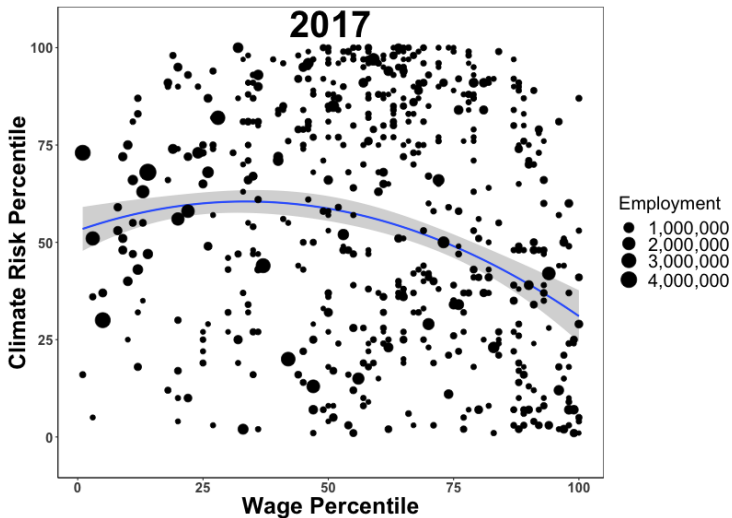
Select Occupations Exposure and Income Percentiles

Occupation	Exposure Percentile	Income Percentile
Lawyers	9	97
Chemistry Teachers, Postsecondary	28	84
Welders, Cutters, Solderers, and Brazers	67	40
Parking Lot Attendants	79	4
Construction Laborers	92	26
Ship Engineers	93	78
Farmworkers and Laborers	94	5
Structural Iron and Steel Workers	98	58
Pile-Driver Operators	99	65
Landscaping and Groundskeeping Workers	100	12

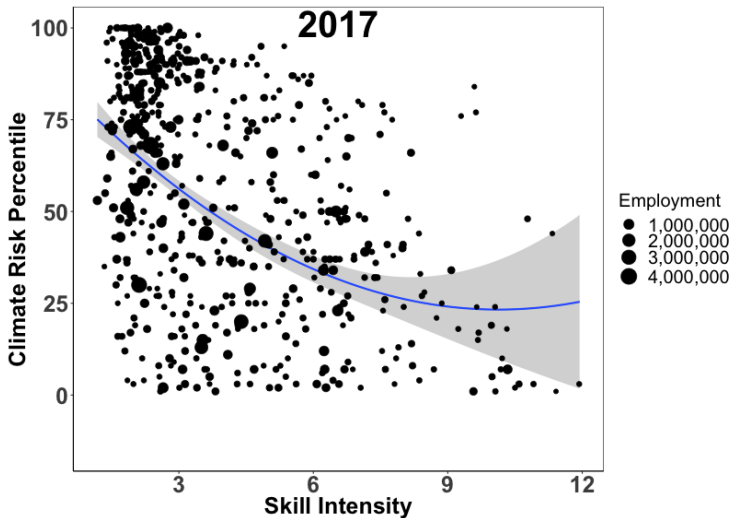
Exposure (θ): time outdoors, indoors w, w/out AC, exposed to extremes⁸

⁸Data on exposure by 6-digit occupation SOC code (n=625 occupations, t=2006-2018)

Heat and Labor: Compensating Differentials



Heat and Labor: Compensating Differentials



Heat and Labor: Institutions

Labor supply responses, realized health risks, may depend contractual arrangement

- e.g. piece-rate vs hourly vs salaried



Heat and Labor: Institutions

Labor supply responses, realized health risks, may depend contractual arrangement

- e.g. piece-rate vs hourly vs salaried



Policymakers may regulate workplace temperature exposure:

- e.g. California worker heat-illness prevention standard (circa-2006)



Recap

- Distribution of climate damages matters for policy
- Emerging evidence suggests temperature impacts may be regressive: both across and within countries
- Important work to be done in understanding role of adaptation investment and possible departures from first-best adaptation frontier

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Temperature Exposure as Occupational Disamenity

Extreme temperature can influence...

- 1 Income volatility (productive amenity)
 - without AC: $+1^{\circ}\text{C} \rightarrow -2\%$ to -4% manufacturing productivity⁹
- 2 Thermal comfort (consumptive amenity)
 - WTP from housing markets: 2%-3% of income per 90°F day¹⁰
- 3 Health capital (productive and consumptive)

⁹(Hsiang, 2010; Somanathan et al., 2018)

¹⁰(Albouy et al., 2016; Sinha et al., 2017)

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Assess causal impact of temperature and workplace injury risk:

- CA Worker's comp (n=17m, t=2000-2018); BLS microdata (1992-2017)
- Quasi-experimental variation in daily temperature by zip code
- Extreme temperature ($>90^{\circ}\text{F}$ +, $<32^{\circ}\text{F}$) increases workplace injury risks substantially: $\rightarrow +1$ to $+3\%$ weekly injury risk per day

⁹(Hsiang, 2010; Somanathan et al., 2018)

¹⁰(Albouy et al., 2016; Sinha et al., 2017)

Regulatory Environment



Learning Chinese

Source: Global Times Published: 2016/6/14 19:33:01

E-Paper Mobile



今天太热了！可惜我还得上班

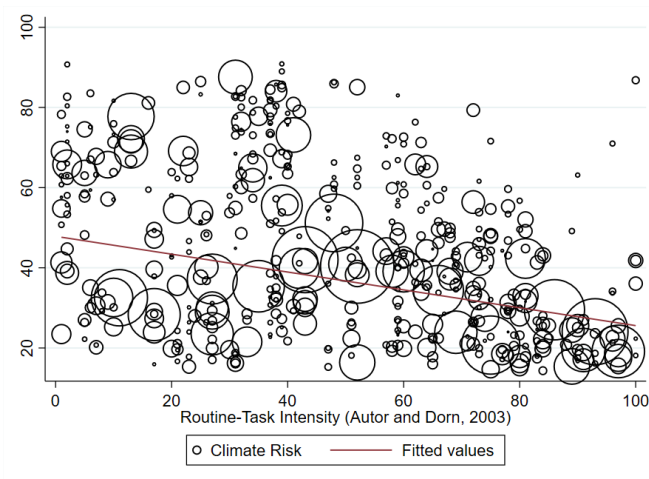
A: It's way too hot today!
Too bad I still have to work.

别闷闷不乐了,酷暑时期上班,可享受高温补贴哦!

B: Don't let it get you down. Workers that work during sweltering summer days have a right to a high heat subsidy!

Climate Change and Skill-Biased Technical Change

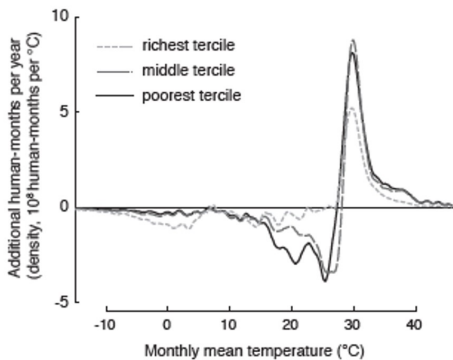
Does automation push low-skill workers into more climate-exposed jobs?



If so, human capital investment may be an important adaptation strategy

Globally, Poorer places predicted to experience more extreme heat

B Global exposure to changes in temperature due to climate change, by income



Climate, Conflict and Labor Markets: Evidence from Colombia's Illegal Drug Production

Maria Cecilia Acevedo





Research Question and Contribution

- What is the causal effect of weather-induced agricultural shocks on labor market conditions and forced displacement?
- Two literatures:
 - Climate and conflict (Burke, Hsiang and Miguel, 2015)
 - Role that institutional quality plays to help explain the directions and magnitudes of the impact of weather fluctuations on conflict through their effect on economic outcomes.
 - Economics of labor coercion (Acemoglu & Wolitzky, 2011, Dippel, Greif and Trefler, 2015).
 - Individual data and use of satellite-generated information to the analysis of coerced labor
 - Analysis of current phenomenon of coca planting and exploitation by non-State armed actors, my research can inform illegal drug policy as well as rural development policies.
- Context of this study is the Colombian coca farming activity, which is strongly controlled by armed illegal groups that benefit financially from this activity.
 - Coca farming contracts enforced with violence

Rainfall and Coca Leaf Productivity

- Matching data from 11,624 coca leaf harvests and satellite gridded rainfall information, I estimate that rainfall and coca yield are positively associated

$$Y_{pt} = \delta_p + \nu_t + \psi \text{Rainfall}_{mt} + \varepsilon_{pt}$$

Table 2: Effect of rainfall on coca yield (First-Stage) Plot Panel Data

	(1)	(2)	(3)
		Dep. variable: Coca yield, t (2004-2010)	
Rain, t	0.440 (0.138)***	0.337 (0.148)*	0.402 (0.117)***
Time trend	No	No	Yes
Plot indicator	No	Yes	Yes
R-squared	0.036	0.036	0.172
N	11,624	11,624	11,624

Notes: Clustered standard errors at municipal level are in parentheses. Sample includes only coca municipalities. Each observation is at the plot-municipality-month-year level. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

- Standard economic theory:
 - Rising productivity should increase wages

Labor Market Responses to Productivity Shocks

- What is the labor market response to good rainfall in coca suitable areas
 - Coca suitable: any municipality with positive amount of coca plants via satellite at least once
 - Outcomes:
 - Log (Real labor earnings per hour + 1)
 - Probability of unemployment
 - Data:
 - 70,000 individual labor market information in 164 coca suitable municipalities

$$Y_{ijmy} = \delta_j + \nu_{my} + \beta t_s + \psi \text{Rainfall}_{jmy} + \alpha' X_{ijmy} + \varepsilon_{ijmt}$$

- Increasing production due to good weather rises labor demand but labor income remains constant

Conceptual framework

- In a labor coercion model, the participation constraint of the coca farmer can be expressed as:

$$Wage - Effort \geq \bar{u} - coercion$$

- Farmer participates in coca farming when payoff from cultivating coca plants is at least as large as effective outside option
- If not -> Displacement
 - Farmers are able to leave the coca sector rather than stay and accept their coca planting contract
- Outside option
 - Limited by the coercive system, as non-State armed actors limit farmers' opportunities for earning a living in non-coca opportunities
 - Expansion of coercive institutions reduces effective outside option
- Therefore: expansion of coercion -> lower outside options -> more likely that farmer stays in coca

Hypothesis and empirical approach

- An increase in coca productivity should be associated with expansion efforts by the coercive non-State armed groups and a decrease in forced displacement.
- I use changes in production that are not caused by non-State actors or coca farmers, but are due solely to random weather draws from the climate distribution, to examine forced displacement in coca-suitable areas.
- More production due to good rainfall →
 - More expansion efforts (+ confrontations, mayor killings)
 - Lower displacement

Results I: Effect of Rainfall on Forced Displacement (Negative Binomial)

$$D_{jmy} = \delta_m \exp(\nu_{my} + \beta t_s + \psi \text{Rainfall}_{jmy} + \varepsilon_{jmt})$$

Dependent variable	(1)	(2)	(3)	(4)
	Percentage change in Displacement			
	Coca areas		Non-coca areas	
Rain	-1.22*** (0.223)	-1.18*** (0.215)	-0.137 (0.307)	0.07 (0.299)
Chi-square test State time trends (p-value)	1542.25 (0.000)	1481.97 (0.000)	5012.32 (0.000)	4720.93 (0.000)
Chi-square test month*year terms (p-value)	3988.76 (0.000)	4172.55 (0.000)	4558.27 (0.000)	4846.00 (0.000)
Controls for Population	No	Yes	No	Yes
Municipality fixed effects	Yes	Yes	Yes	Yes
Month*Year fixed effects	Yes	Yes	Yes	Yes
State time trends	Yes	Yes	Yes	Yes
Observations	23,088	23,088	57,642	57,642
Number of municipalities	296	296	739	739

Notes: Each observation represents a municipality-year-month. Variables not shown include municipality fixed effects, month*year fixed effects and linear time trends per State. Coca is a time-invariant variable defined as an indicator (1 or 0) of coca presence during the period 1999-2010. If a municipality shows a least one positive value of coca presence in the municipality during the period 1999-2010, this variable takes a value of 1, and 0 otherwise. The dependent variable is defined as displaced population in the municipality. Rainfall is measured in mm. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

An additional millimeter of precipitation above the municipality mean decreases forced displacement by 1.22% in coca-suitable areas

In non-coca areas the effect of positive rainfall shocks is smaller and insignificant.



Results II: Instrumental Variables Evidence

- Second test : do high productivity months within coca growing municipalities witness lower forced displacement?
- Match coca leaf yield data with local violence in a small sample of municipalities with rich harvest data.
- Changes in forced displacement are explained by coca leaf yield variations, and I instrument changes in coca leaf yield with rainfall
- Since rainfall affects many social phenomena simultaneously (Dell, Jones and Olken, 2014)
 - set of municipalities that are highly dependent on coca plantation and transformation into cocaine
 - follow cocaleros (coca farmers) during every month for one year from these municipalities, matching their yields to local monthly violence.
- IV estimation requires
 - First stage: shown before
 - Exclusion restriction: rainfall affects violence only through its effect on coca leaf yield in coca growing areas

Results: Effect of Coca Leaf Yield on Forced Displacement (IV)

$$D_{mt} = \delta_p + \beta_t + \gamma Y_{pt} + \varepsilon_{mt}$$

	(1)	(2)	(3)
	Dep. variable: Forced displacement (2004-2010)		
Yield	-2.136	-6.089	-4.776
	(0.376)***	(1.509)***	(1.165)***
Instrument	Rain	Rain	Rain
Linear time trend	No	No	Yes
Plot indicator	No	Yes	Yes
R-squared	0.0012	0.0012	0.0025
N	11,088	11,088	11,088

Note: Sample includes only coca municipalities. Each observation is at the plot-municipality-month-year level. Clustered standard errors at municipal level are in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

Expect ψ to be negative

- Coerced sector yields higher returns with better rainfall
- Coercion efforts should increase in higher productivity months compared to lower productivity months
- Less coca farmers should be able to leave the coca contract in higher rainfall months than in lower rainfall periods
- One additional arroba of coca leaf per hectare harvested per month is associated with a reduction of forced displacement of 4.77 people on average, and this estimate is significant at all statistical levels.
- Displacement mean in coca suitable areas is 35.85 people.

Additional Results: Effect of Coca Leaf Yield on Clashes Between non-State Armed Actors and Government (IV)

- Expansion efforts by non-State armed groups increase with rising productivity

Table 8: Effect of Coca Yield on Clashes Between Illegal Groups and Government Forces (Second-Stage)

	(1)	(2)	(3)
	Dep. variable: Clashes (2004-2010)		
Yield	0.004	0.086	0.067
	(.001)***	(0.018)***	(0.013)***
Instrument	Rain	Rain	Rain
Linear time trend	No	No	Yes
Plot indicator	No	Yes	Yes
R-squared	0.0003	0.0003	0.0011
N	11,088	11,088	11,088

Note: Sample includes only coca municipalities. Each observation is at the plot-municipality-month-year level. Clustered standard errors at municipal level are in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

Additional Results: Effect of Coca Leaf Yield on Democratically Elected Mayor Killings (IV)

Table 9: Effect of Coca Yield on Mayor Casualties (Second-Stage)

	(1)	(2)	(3)
	Dep. variable: mayor casualties (2004-2010)		
Yield	0.000 (0.000)**	0.001 (0.000)*	0.001 (0.000)**
Instrument	Rain	Rain	Rain
Linear time trend	No	No	Yes
Plot indicator	No	Yes	Yes
R-squared	0.0002	0.0002	0.0002
N	11,088	11,088	11,088

Note: Sample includes only coca municipalities. Each observation is at the plot-municipality-month-year level. Clustered standard errors at municipal level are in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

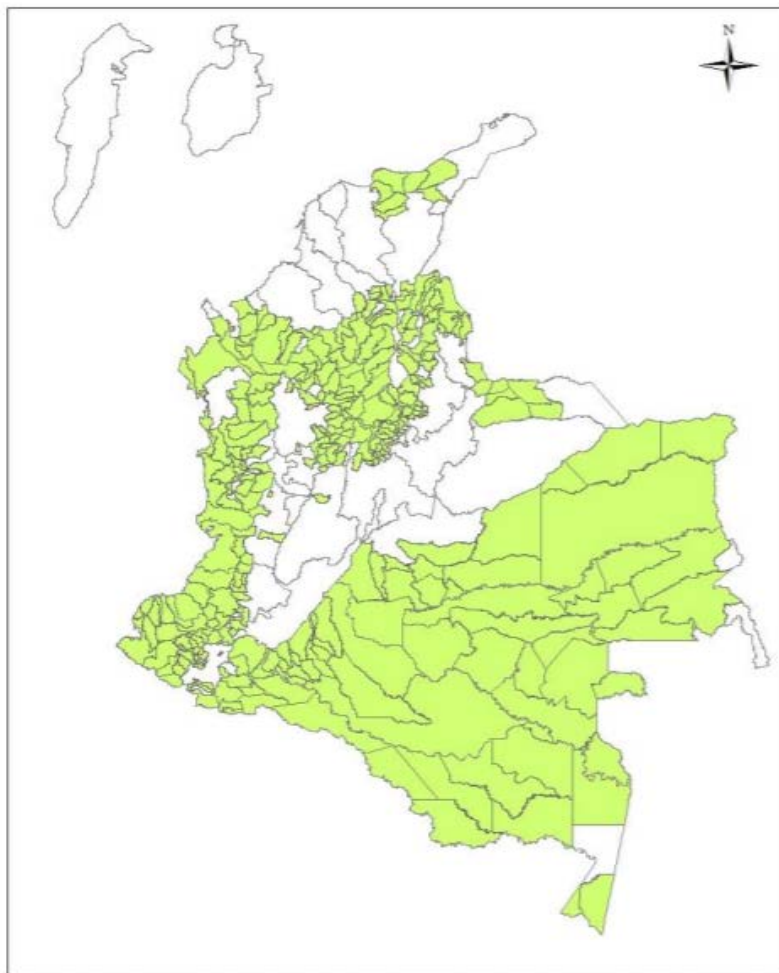


Main messages

- Shocks and institutions in labor markets
 - In fragile institutional environments, positive productivity changes may lead to more confrontations between non-State armed groups; government authorities face larger risks of being killed in good times rather than in bad times
- Global crises of refugees: when and why
 - In coerced labor markets, refugees will be more able to leave their places of origin when their coercive activity experiences a bad shock rather than a good shock

Annex

Municipalities where coca plants were cultivated between 1999-2011



Notes: Municipalities in green correspond to coca-suitable municipalities. Coca suitability is defined as a binary variable that takes on the value of 1 if the municipality has had coca presence as identified by satellite during at least one year since 1999-2011. Sources: Coca satellite data by UNODC, municipality limits by Agustin Codazzi.

Exclusion restriction

Elementary school



Infrastructure in coca region



- 82% percent of coca growers have coca as the main household's income source
- Most of the coca farmers are landless
- Average distance between coca region and closest local market is 60 miles
- Excess rainfall is less good for legal crops than coca since the coca leaf plant has been modified through history to maximize the levels of its alkaloid
 - Maximizes level of cocaine but kills the pests that are associated with abnormally high precipitation
- Coca bushes are exclusively rain-fed as irrigation is non-existing
- Individuals rely heavily on coca for their economic transactions, including as currency
- Effect of government spraying of coca bushes on yield is indistinguishable from zero (Rozo, 2013)

Additional Results (II): Effect of Negative Weather Shock on Forced Displacement

- As predicted by coercion labor models, a negative shock to coca production is associated with more forced displacement

$$Displacement_{my} = \delta_m + \nu_y + \tau NegativeWeatherShock_{imt} + X'\beta + \varepsilon_{my}$$

	(1)	(2)
	Dep. variable: Displaced population	
Self-reported negative weather shock	331.283 (194.11)*	316.10 (157.77)**
Owner		26.29 (60.05)
Land area		1.24 (0.914)
Migrant		114.58 (97.42)
Male		-0.89 (22.91)
Age		-0.88 (1.46)
Coca leaf specie	No	Yes
Municipality fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
R-squared	0.83	0.84
Number of municipalities	57	57
N	1,763	1,763

Notes: Regressors not shown include municipality and year indicators. Each observation is at farmer level. Clustered standard errors at municipal level are in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.