Temperature and Growth: A Panel Analysis of the United States

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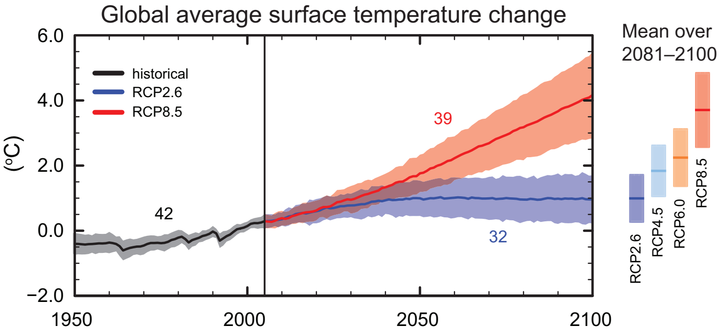
Motivation



(Source: IPCC Report 2014)

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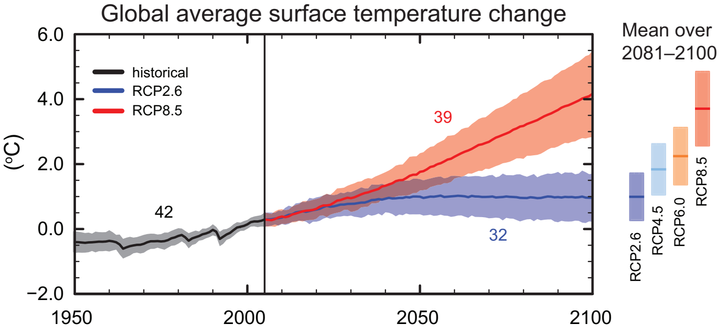

(Source: IPCC Report 2014)

- Temperatures are expected to go up as much 4^{o}C over next century

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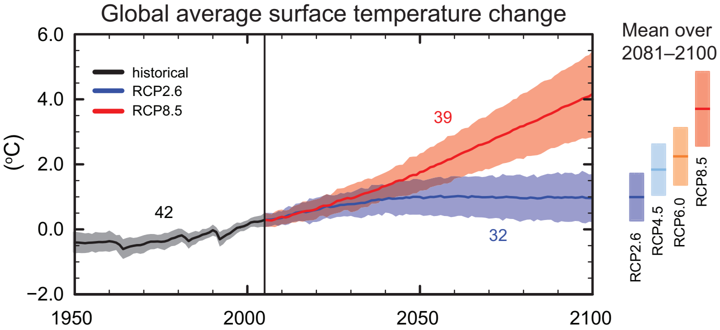

(Source: IPCC Report 2014)

- Temperatures are expected to go up as much 4^oC over next century
- Is there a link between rising temperatures and economic growth?

Existing literature

Evidence for

- developing countries: Dell, Jones and Olken (2012, 2014), Hsiang Burke (2013), Barrios, Bertinelli and Strobl (2010)
- U.S. agricultural output: Fisher Hanemann Roberts Schlenker (2012), Lybbert Smith Sumner (2013), Deschenes and Greenstone (2012)
- U.S. labor supply: Zivin and Neidell (2014)

This paper

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- Answers this question for the United States' GDP

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  1. **large effects** of Summer (negative) and Fall (positive) temperatures on states' GDP growth

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  1. **large effects** of Summer (negative) and Fall (positive) temperatures on states' GDP growth
  2. negative effect of Summer temperature getting stronger over time

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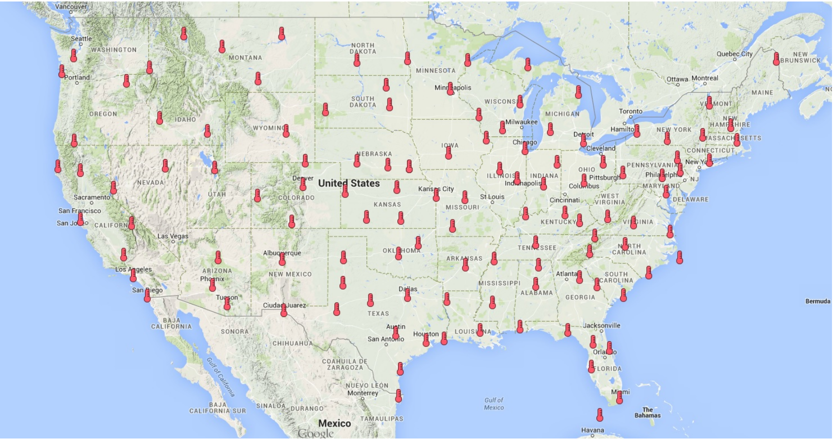
- Answers this question for the United States' GDP
- Employs a panel of US states' weather and GSP data
- Finds:
  1. **large effects** of Summer (negative) and Fall (positive) temperatures on states' GDP growth
  2. negative effect of Summer temperature getting stronger over time
  3. in net, rising temperatures may decrease US growth by up to 1/3 over next century

Roadmap

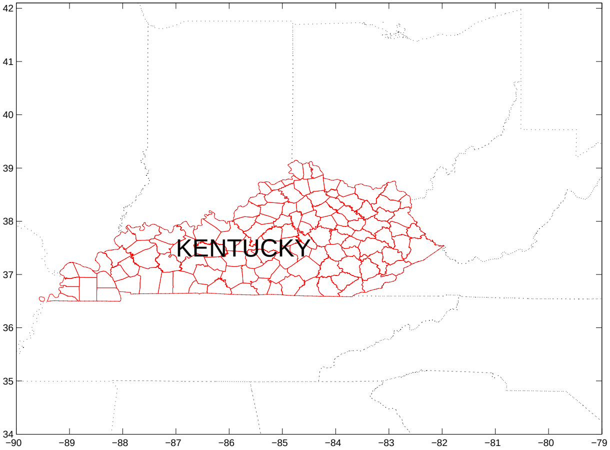
1. Data
2. Empirical Evidence
3. Interpretation
4. Welfare Analysis

Weather Stations



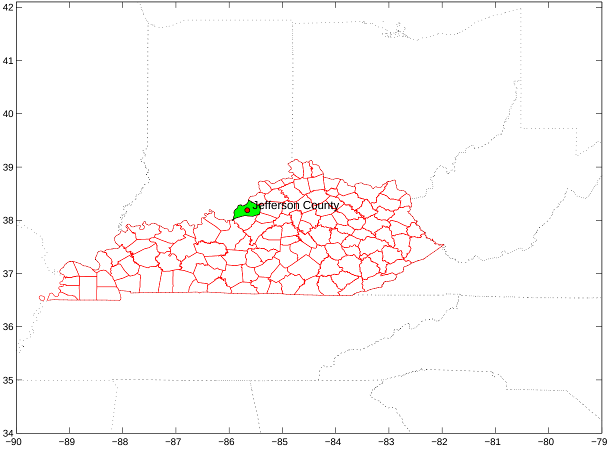
135 Weather Stations (Source: NOAA Northeast Regional Climate Center)

Calculation of State Level Weather



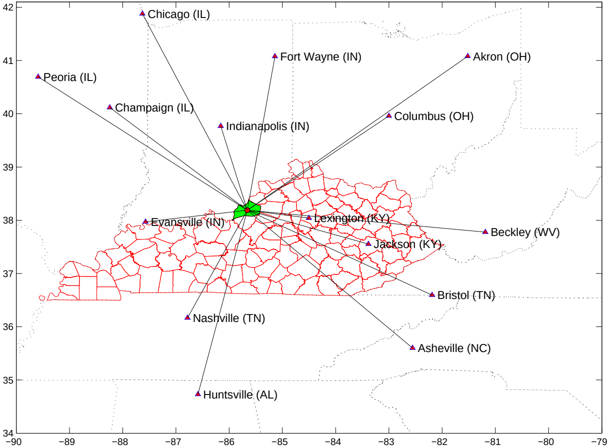
Kentucky has 120 Counties

Calculation of State Level Weather



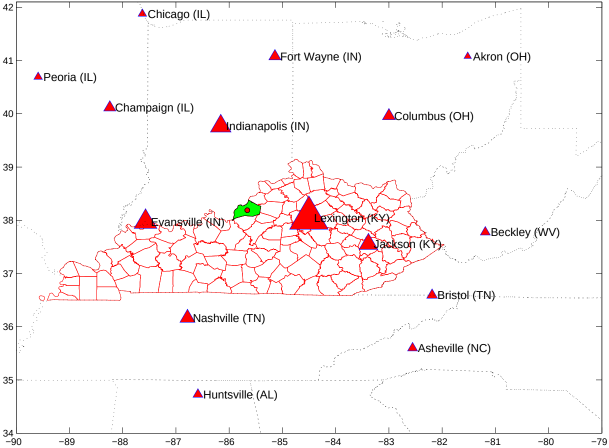
For each County we find the coordinates of the center

Calculation of State Level Weather



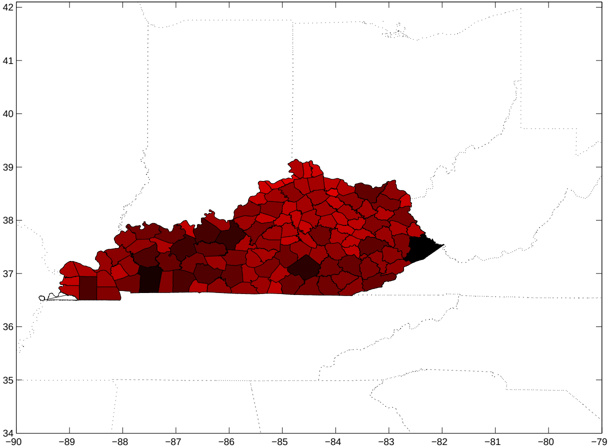
We calculate the distance between County and Weather Stations

Calculation of State Level Weather



We weight Weather Stations as an inverse function of their distance

Calculation of State Level Weather



We aggregate to State level by weighting each county according to area or population

Data sources

- Economic data: BEA, sample 1957-2012
- Population and Area: CENSUS
- Weather: NOAA

Empirical Evidence

- Time series regression (US aggregate data)
- Panel regression
- Combine results with trends in temperature

Time Series Regressions

Whole Year	Winter	Spring	Summer	Fall
−0.396 (0.382)				

- Time series regressions with Annual Temperature: insignificant

Time Series Regressions

Whole Year	Winter	Spring	Summer	Fall
−0.396	−0.071	−0.027	−0.414	0.042
(0.382)	(0.179)	(0.334)	(0.385)	(0.287)

- Time series regressions with Annual Temperature: insignificant
- Time series regressions with Seasonal Temperatures: insignificant

Time Series Regressions

Whole Year	Winter	Spring	Summer	Fall
−0.396	−0.071	−0.027	−0.414	0.042
(0.382)	(0.179)	(0.334)	(0.385)	(0.287)

- Time series regressions with Annual Temperature: insignificant
- Time series regressions with Seasonal Temperatures: insignificant
- Annual coefficient similar to Summer coefficient

Panel Regressions

	Whole Year	Winter	Spring	Summer	Fall
Whole country					
North					
South					
Midwest					
West					

Panel Regressions

	Whole Year	Winter	Spring	Summer	Fall
Whole country	0.006				
	(0.111)				
North					
South					
Midwest					
West					

- Annual regressions are still inconclusive

Panel Regressions

	Whole Year	Winter	Spring	Summer	Fall
Whole country	0.006				
	(0.111)				
North	0.343				
	(0.339)				
South	0.283				
	(0.303)				
Midwest	−0.212				
	(0.235)				
West	−0.144				
	(0.203)				

- Annual regressions are still inconclusive
- Similar results for Regions

Panel Regressions

	Whole Year	Winter	Spring	Summer	Fall
Whole country	0.006	0.001	0.003	-0.154^{**}	0.102^{*}
	(0.111)	(0.049)	(0.065)	(0.072)	(0.055)
North	0.343				
	(0.339)				
South	0.283				
	(0.303)				
Midwest	-0.212				
	(0.235)				
West	-0.144				
	(0.203)				

- Annual regressions are still inconclusive
- Similar results for Regions
- Summer and Fall temperatures affect economic growth
  - Rising Summer temperatures decrease growth
  - Rising Fall temperatures increase growth

Panel Regressions

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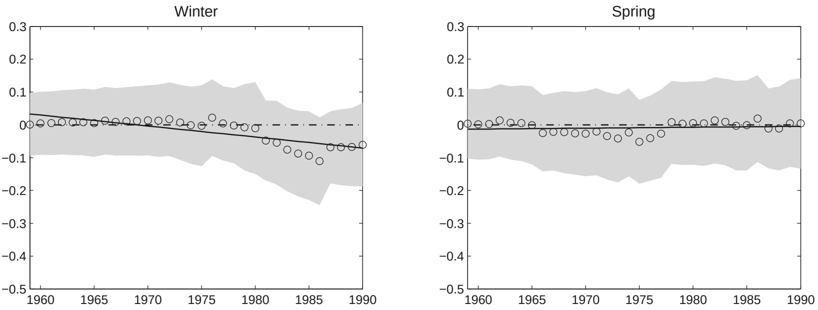
Whole country	0.006	0.001	0.003	−0.154**	0.102*
	(0.111)	(0.049)	(0.065)	(0.072)	(0.055)
North	0.343	0.329*	0.065	0.240	−0.255
	(0.339)	(0.173)	(0.296)	(0.257)	(0.233)
South	0.283	−0.087	0.152	−0.326**	0.571***
	(0.303)	(0.167)	(0.159)	(0.163)	(0.194)
Midwest	−0.212	0.010	−0.158	0.043	−0.116
	(0.235)	(0.089)	(0.144)	(0.162)	(0.128)
West	−0.144	−0.000	−0.155	0.028	−0.006
	(0.203)	(0.096)	(0.143)	(0.154)	(0.167)

- Annual regressions are still inconclusive
- Similar results for Regions
- Summer and Fall temperatures affect economic growth
    - Rising Summer temperatures decrease growth
    - Rising Fall temperatures increase growth
- Results mostly driven by South

How stable are the coefficients?



Effect of Winter and Spring temperatures very stable

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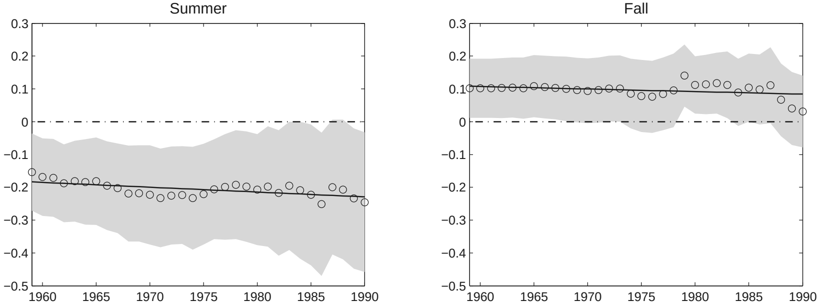

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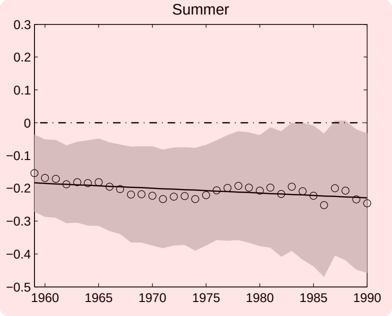
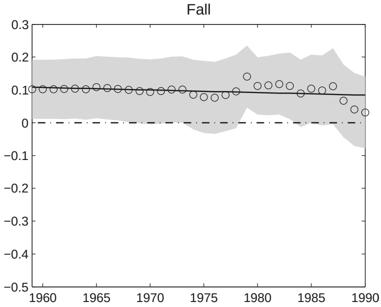
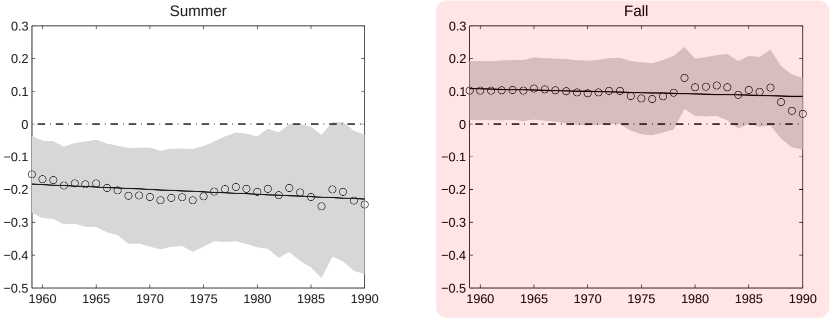




Summer effect is getting stronger over time

Full sample estimate	-0.154
1990-2012 estimate	-0.245

How stable are the coefficients?



Fall effect is getting weaker over time

Full sample estimate	0.102
1990-2012 estimate	0.031

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- Year to year: net effect is small

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- Long Horizons?

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- Year to year: net effect is small
- Long Horizons?
  $\rightarrow$ It depends on relative trends in Summer and Fall temperatures

Effect over Long Horizons

- Time trends in Seasonal temperatures

		Whole Year	Winter	Spring	Summer	Fall
Country	Trend	0.041***	0.071***	0.034***	0.036***	0.021**
		(0.006)	(0.015)	(0.010)	(0.008)	(0.009)
	AR(1)	0.077	−0.048	0.143	0.061	−0.212
		(0.149)	(0.146)	(0.143)	(0.141)	(0.139)

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- Summer temperature is expected to rise twice as much as Fall temperature

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- Impact over the next century

$$\underbrace{0.036 \times 100}_{\text{Expected rise in Summer temperature}} \qquad \underbrace{0.021 \times 100}_{\text{Expected rise in Fall temperature}}$$

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- Impact over the next century

$$\underbrace{-0.154}_{\text{Summer coef. (Full Sample)}} \times \underbrace{0.036 \times 100}_{\text{Expected rise in Summer temperature}} + \underbrace{0.102}_{\text{Fall coef. (Full Sample)}} \times \underbrace{0.021 \times 100}_{\text{Expected rise in Fall temperature}} =$$

Effect over Long Horizons

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Effect over Long Horizons

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	AR(1)	0.077	−0.048	0.143	0.061	−0.212
		(0.149)	(0.146)	(0.143)	(0.141)	(0.139)

- Summer temperature is expected to rise twice as much as Fall temperature

- Impact over the next century

$$\underbrace{\boxed{-0.245}}_{\text{Summer coef. (1990- Sample)}} \times \underbrace{0.036 \times 100}_{\text{Expected rise in Summer temperature}} + \underbrace{\boxed{0.031}}_{\text{Fall coef. (1990- Sample)}} \times \underbrace{0.021 \times 100}_{\text{Expected rise in Fall temperature}} = \boxed{-0.82\%}$$

Take-away message

To capture the effect of rising temperature on US growth, we need to:

1. break down annual temperatures into seasonal temperatures
2. look at the differences in seasonal temperature trends

Welfare Analysis

- Representative agent with Recursive Preferences

$$U_t = (1-\delta)\log C_t + \frac{\delta}{1-\gamma}\log E_t \exp\{(1-\gamma)U_{t+1}\}$$

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- Representative agent with Recursive Preferences

$$U_t = (1-\delta)\log C_t + \frac{\delta}{1-\gamma}\log E_t \exp\{(1-\gamma)U_{t+1}\}$$

- Consumption dynamics [Business As Usual]

$$\Delta c_t = 0.02 - 0.154 \cdot temp_t^{sum} + 0.102 \cdot temp_t^{fall} + 0.02 \cdot \varepsilon_{c,t}$$

where

$$temp_t^{sum} = 0.036 \cdot t + 0.0078 \cdot \varepsilon_t^{summ}$$
$$temp_t^{fall} = 0.021 \cdot t + 0.0116 \cdot \varepsilon_t^{fall}$$

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- Representative agent with Recursive Preferences

$$U_t = (1-\delta)\log C_t + \frac{\delta}{1-\gamma}\log E_t \exp\{(1-\gamma)U_{t+1}\}$$

- Consumption dynamics [Intervention]

$$\Delta c_t = 0.02 - 0.154\cdot(1-\Delta^{\lambda})\cdot temp_t^{sum} + 0.102\cdot(1-\Delta^{\lambda})\cdot temp_t^{fall} + 0.02\cdot\varepsilon_{c,t}$$

where

$$temp_t^{sum} = 0.036\cdot t + 0.0078\cdot\varepsilon_t^{summ}$$
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- Welfare gains of
  1. Adaptation (Δ^{λ})
  2.

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- Welfare gains of
  1. Adaptation (Δ^{λ})
  2. Mitigation (Δ^{β})

Welfare Analysis

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- Welfare gains of
  1. Adaptation (Δ^{λ})
  2. Mitigation (Δ^{β})

Welfare Analysis (cont'd)

Calculate the permanent changes in

- the level of consumption (Δ_0)
- the growth rate of consumption (Δ_1)

that make the agent indifferent between living in

- Business As Usual economy
- Intervention economy

Welfare Analysis: Results

Panel A: permanent reduction of the level (Δ_0)

		$\boldsymbol{\Delta^{\beta}}$					
		0%	20%	40%	60%	80%	100%
$\hat{\Delta}$	0%	0.0	−0.1	−0.1	−0.2	−0.2	−0.3
	20%	−0.1	−0.1	−0.1	−0.2	−0.2	−0.3
	40%	−0.1	−0.1	−0.2	−0.2	−0.2	−0.3
	60%	−0.2	−0.2	−0.2	−0.2	−0.3	−0.3
	80%	−0.2	−0.2	−0.2	−0.3	−0.3	−0.3
	100%	−0.3	−0.3	−0.3	−0.3	−0.3	−0.3

Panel B: permanent growth rate reduction (Δ_1/μ_c)

		$\boldsymbol{\Delta^{\beta}}$					
		0%	20%	40%	60%	80%	100%
$\hat{\Delta}$	0%	0.0	−2.8	−5.6	−8.4	−11.2	−14.0
	20%	−2.8	−5.0	−7.3	−9.5	−11.8	−14.0
	40%	−5.6	−7.3	−9.0	−10.6	−12.3	−14.0
	60%	−8.4	−9.5	−10.6	−11.8	−12.9	−14.0
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	60%	−0.2	−0.2	−0.2	−0.2	−0.3	−0.3
	80%	−0.2	−0.2	−0.2	−0.3	−0.3	−0.3
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	80%	−11.2	−11.8	−12.3	−12.9	−13.4	−14.0
	100%	−14.0	−14.0	−14.0	−14.0	−14.0	−14.0

Δ^{λ} 20% *Adaptation*

Δ^{β} 00% *Mitigation*

Welfare Analysis: Results

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	40%	−0.1	−0.1	−0.2	−0.2	−0.2	−0.3
	60%	−0.2	−0.2	−0.2	−0.2	−0.3	−0.3
	80%	−0.2	−0.2	−0.2	−0.3	−0.3	−0.3
	100%	−0.3	−0.3	−0.3	−0.3	−0.3	−0.3

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Give up:

Δ^{λ} 20% *Adaptation*

Δ^{β} 00% *Mitigation*

$\Rightarrow$

0.10% of current consumption level

2.80% of current consumption growth

Welfare Analysis: Results

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	40%	−0.1	−0.1	−0.2	−0.2	−0.2	−0.3
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	80%	−11.2	−11.8	−12.3	−12.9	−13.4	−14.0
	100%	−14.0	−14.0	−14.0	−14.0	−14.0	−14.0

Give up:

Δ^{λ} 60% *Adaptation*

Δ^{β} 60% *Mitigation*

$\Rightarrow$

0.20% of current consumption level

11.8% of current consumption growth

Robustness checks

Results are robust to:

- alternative weighting schemes ▸ Details
- controlling for precipitation ▸ Details
- controlling for temperature volatility ▸ Details

Concluding Remarks

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- Analysis informative for Integrated Assessment Models

Extra Slides

Alternative weighting schemes (Back)

	Whole Year	Winter	Spring	Summer	Fall
GSP (varying)	0.010	0.008	−0.008	−0.148*	0.105*
	(0.119)	(0.051)	(0.067)	(0.077)	(0.058)
Area	0.054	0.018	0.012	−0.098	0.079
	(0.123)	(0.062)	(0.074)	(0.066)	(0.063)
Population	0.057	0.028	−0.025	−0.132*	0.131**
	(0.123)	(0.053)	(0.069)	(0.071)	(0.061)

Controlling for Precipitation (Back)

		Whole Year	Winter	Spring	Summer	Fall
USA	Temp.	0.004	0.003	0.008	-0.169^{**}	0.093^{*}
		(0.113)	(0.047)	(0.069)	(0.077)	(0.056)
	Prec.	−0.012	−0.050	−0.044	0.006	0.037
		(0.056)	(0.033)	(0.032)	(0.032)	(0.028)
North	Temp.	0.366	0.333^{*}	0.103	0.122	−0.256
		(0.348)	(0.189)	(0.302)	(0.272)	(0.263)
	Prec.	−0.063	−0.118	−0.098	0.061	0.161
		(0.175)	(0.106)	(0.083)	(0.091)	(0.116)
Midwest	Temp.	−0.232	0.009	−0.164	−0.014	−0.112
		(0.239)	(0.091)	(0.142)	(0.168)	(0.122)
	Prec.	−0.076	0.025	−0.047	−0.013	−0.015
		(0.117)	(0.064)	(0.044)	(0.059)	(0.086)
South	Temp.	0.323	−0.091	0.214	-0.402^{**}	0.561^{***}
		(0.325)	(0.164)	(0.188)	(0.162)	(0.195)
	Prec.	0.056	0.019	-0.083^{*}	0.017	0.058
		(0.125)	(0.055)	(0.049)	(0.061)	(0.056)
West	Temp.	−0.142	0.006	−0.124	0.045	−0.006
		(0.204)	(0.095)	(0.144)	(0.159)	(0.170)
	Prec.	0.133^{*}	0.020	0.092	0.080^{*}	0.003
		(0.072)	(0.041)	(0.082)	(0.045)	(0.033)

Controlling for Temperature Volatility (Back)

		Whole Year	Winter	Spring	Summer	Fall
Whole country	Mean	0.004	−0.009	−0.013	−0.138*	0.106*
		(0.111)	(0.050)	(0.062)	(0.071)	(0.055)
	Vol	−0.002	0.002	−0.001	0.002	−0.000
		(0.002)	(0.002)	(0.001)	(0.002)	(0.001)
North	Mean	0.324	0.363**	0.113	0.189	−0.201
		(0.340)	(0.176)	(0.296)	(0.251)	(0.214)
	Vol	−0.004	−0.004	0.001	−0.003	−0.003
		(0.006)	(0.005)	(0.004)	(0.004)	(0.003)
Midwest	Mean	−0.212	0.009	−0.177	0.047	−0.117
		(0.236)	(0.085)	(0.149)	(0.154)	(0.121)
	Vol	−0.001	0.004	0.002	0.003	−0.001
		(0.003)	(0.005)	(0.003)	(0.002)	(0.002)
South	Mean	0.273	−0.121	0.135	−0.280*	0.580***
		(0.299)	(0.173)	(0.154)	(0.154)	(0.208)
	Vol	−0.005	0.002	0.006*	0.003	−0.004
		(0.005)	(0.003)	(0.003)	(0.005)	(0.003)
West	Mean	−0.146	−0.004	−0.148	0.040	−0.031
		(0.204)	(0.099)	(0.144)	(0.155)	(0.181)
	Vol	−0.000	−0.001	−0.000	0.002	−0.001
		(0.003)	(0.002)	(0.002)	(0.003)	(0.002)