Temperature and Growth: A Panel Analysis of the United States

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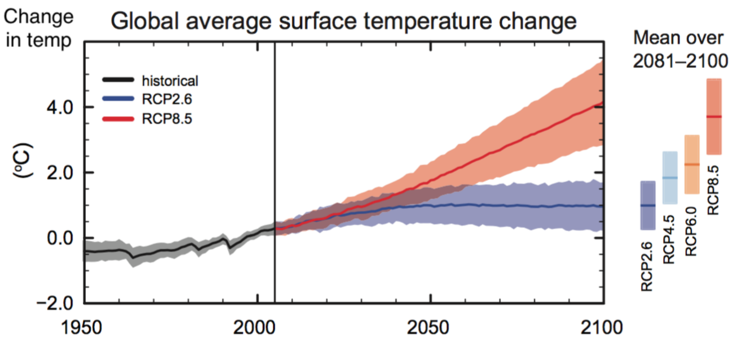
Motivation



(Source: IPCC Report 2014)

- Temperatures likely to continue rising over the century
- What are effects of rising temperatures on economic growth?

Existing literature

Evidence for developing countries

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- Weather shocks appear to have little effect on rich countries' GDP (Dell, Jones and Olken, 2012, 2014)

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  - Transitory growth effects of cold winter: Bloesch and Gourio (2015)

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  - Disaggregate national GDP by using states' GDP
  - Disaggregate annual weather data down to seasons

Our findings

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  - Pervasive summer effects on many industries
  - Effects particularly strong for U.S. South
  - Effects seem to operate through reduction in labor productivity
  - Rising temp. may decrease US growth by up to 1/3 over the next century

Roadmap

1. Data
2. Main results
3. Economic mechanisms
4. Additional results

Data

Data sources

- Economic data: BEA and BLS, sample 1957-2012
- Population and Area: CENSUS
- Weather (daily temperature [in F], precipitation & snowfall at weather stations): NOAA Northeast Regional Climate Center

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  - E.g., assume average Jan temp in Chicago 25°F, a raw observation of 30°F becomes $+5$°F, reflecting an unusually warm day for Chicago

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- State level: Aggregate all counties in each state, weighted by county's area or population
- Aggregate daily observations into seasons (winter: Ja-Fe-Ma, spring: Ap-Ma-Ju,..., Hansen et al., 2012)

Main Results

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- Regress on seasonal temperature average:

$$\Delta y_t = \sum_{s=1}^{4} \beta_s Temp_{s,t} + \rho \Delta y_{t-1} + \varepsilon_t$$

Time series regressions on National Aggregate Data

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)

- Using national aggregate data: No significant result (as in Dell et al. 2012)

Panel regressions with state-level data

- Annual temp average:

$$\Delta y_{i,t} = \beta Temp_{i,t} + \rho \Delta y_{i,t-1} + \alpha_i + \alpha_t + \varepsilon_{i,t}$$

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- States are weighted by relative size of their GDP (e.g., TX more weight than ME)

Panel regressions with state-level data

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Whole Year	Winter	Spring	Summer	Fall
0.006	0.001	0.003	-0.154	0.102
(0.111)	(0.049)	(0.065)	(0.072)**	(0.055)*
(0.069)	(0.025)	(0.032)	(0.047)***	(0.040)**

- Significant effects of Summer & Fall temperatures

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    - Rising summer temperature decrease growth
    - Rising fall temperature increase growth

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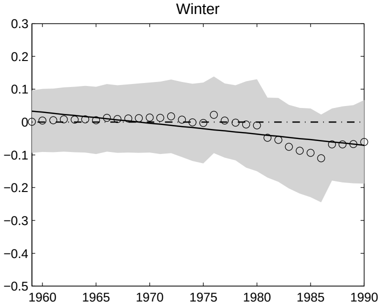

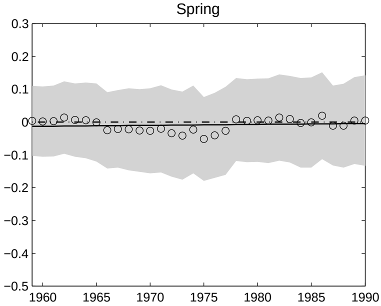

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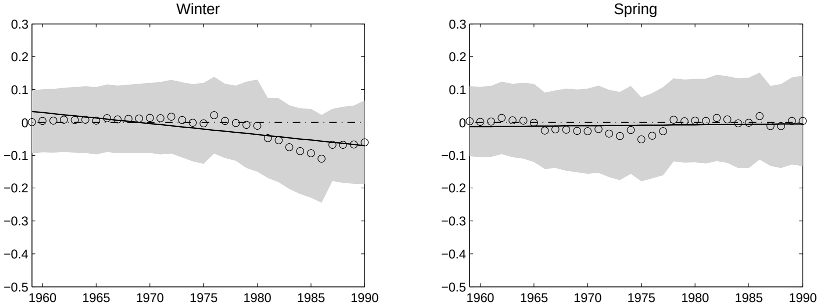

Effects of Winter and Spring continue to be insignificant

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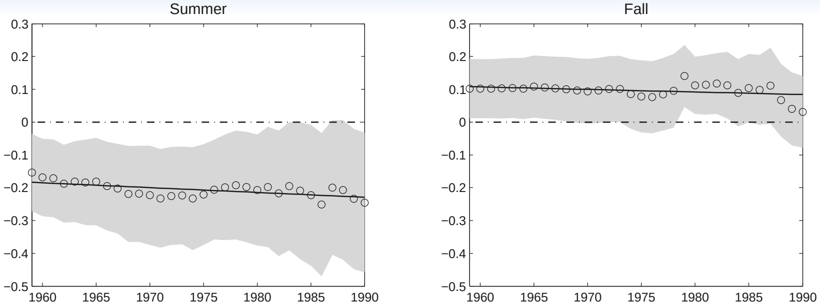

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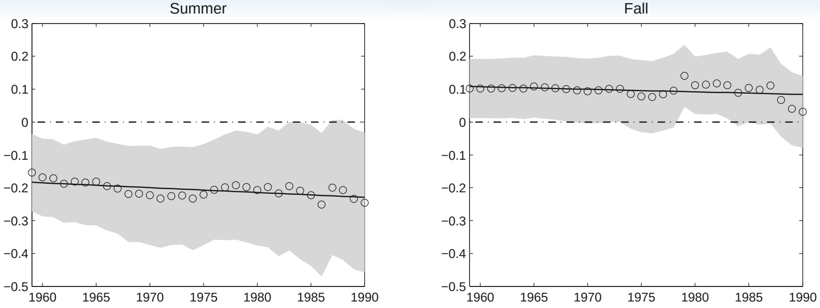

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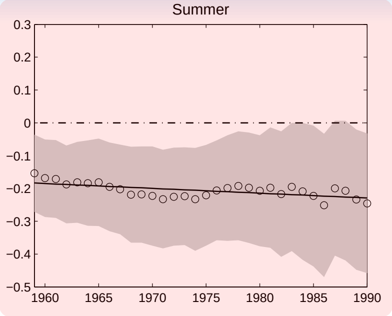

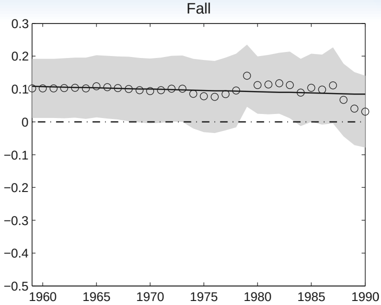

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- Point-estimates of summer effect: -0.154 (full) $\rightarrow$ -0.245 (post-1990)

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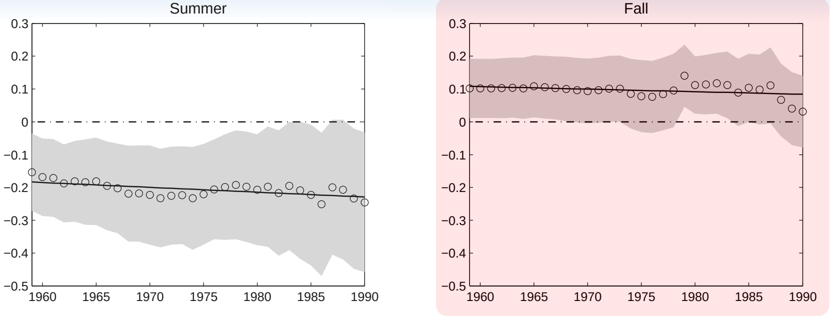

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- Point-estimates of summer effect: -0.154 (full) $\rightarrow$ -0.245 (post-1990)
- Point-estimate of fall effect: 0.102 (full) $\rightarrow$ 0.031 and not significant (post-1990)

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- $H_0 : \beta_s + \beta_{lag,s} = 0$ (i.e., temp only affect GDP level)
- We can reject H_0

Growth v. Level

	Winter	Spring	Summer	Fall
Contempory temp.	−0.008	−0.012	−0.170	0.109
	(0.051)	(0.059)	(0.076)**	(0.050)**
	(0.029)	(0.032)	(0.045)***	(0.038)***
1 yr lagged temp.	0.004	0.121	−0.153	0.066
	(0.053)	(0.063)*	(0.079)*	(0.060)
	(0.023)	(0.039)***	(0.053)***	(0.029)**
Sum of coefficients	−0.004	0.109	−0.323	0.174
	(0.084)	(0.086)	(0.115)***	(0.077)**
	(0.031)	(0.045)**	(0.077)***	(0.052)***
Wald test's *p*-value	[0.961]	[0.208]	[0.007]	[0.027]
	[0.893]	[0.018]	[0.000]	[0.002]

Economic Mechanisms

Effects on labor productivity

is defined as private industries' state-level output/number of employeesEstimate

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	Winter	Spring	Summer	Fall
Productivity	-0.033	-0.020	-0.152	0.132
	(0.067)	(0.065)	$(0.087)^{*}$	$(0.048)^{***}$
	(0.042)	(0.031)	$(0.050)^{***}$	$(0.054)^{**}$

More on employment

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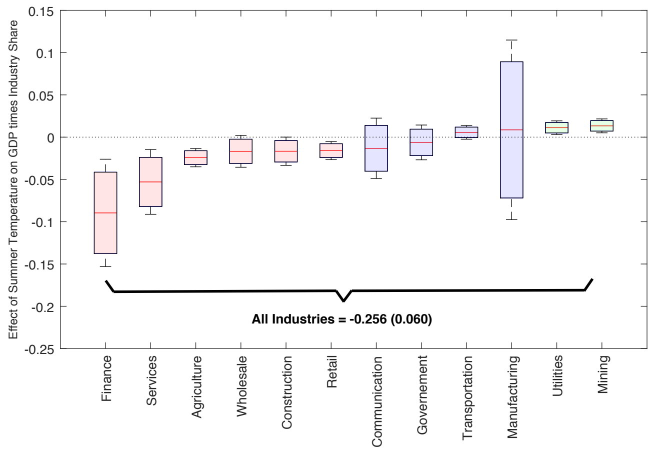
- Found pervasive effects

Industries



Post-1997 estimates. 90 and 95% confidence intervals. “All industries” is sum of all industry coefficients, multiplied by industry share of national GDP. “Finance” refers to “Finance, Insurance, and Real Estate.”

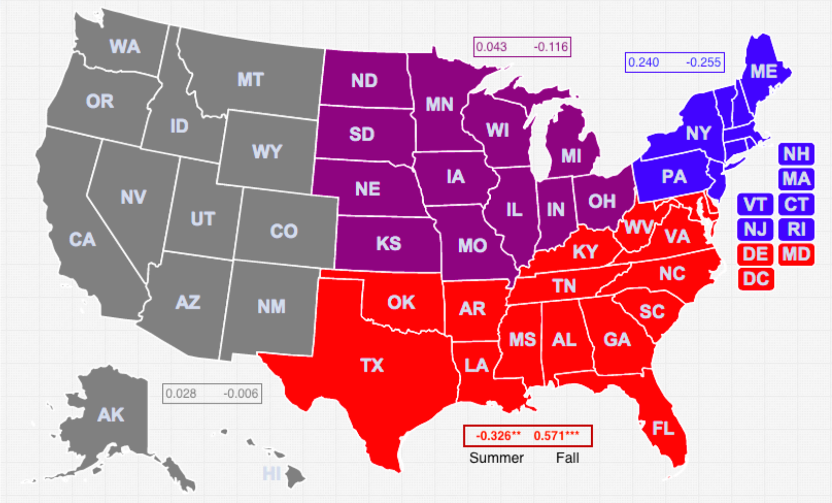
Industries

	Pre-1997	Post-1997	Avg. GDP share (%)
Gross state product	−0.188	−0.250	100
	(0.095)**	(0.197)	
	(0.062)***	(0.067)***	
Services†	0.020	−0.206	25.7
	(0.070)	(0.075)***	
	(0.050)	(0.076)***	
Finance, insurance, real estate	−0.209	−0.437	20.5
	(0.241)	(0.384)	
	(0.228)	(0.158)***	
Manufacturing	−0.058	0.067	12.9
	(0.215)	(0.623)	
	(0.102)	(0.420)	
Government	−0.068	−0.051	12.2
	(0.071)	(0.165)	
	(0.063)	(0.086)	
Retail	−0.052	−0.241	6.6
	(0.073)	(0.189)	
	(0.060)	(0.083)***	
Wholesale	−0.158	−0.284	5.9
	(0.104)	(0.171)*	
	(0.062)**	(0.163)*	
Communication/Information†	−0.235	−0.294	4.5
	(0.088)***	(0.732)	
	(0.092)**	(0.405)	
Construction	−0.224	−0.379	4.4
	(0.236)	(0.446)	
	(0.199)	(0.194)*	
Transportation	0.150	0.189	3.0
	(0.125)	(0.221)	
	(0.196)	(0.138)	
Utilities	0.338	0.621	1.8
	(0.248)	(0.377)*	
	(0.202)*	(0.230)***	
Mining	−0.153	0.954	1.4
	(0.539)	(1.524)	
	(0.572)	(0.300)***	
Agriculture, forestry, fishing	−2.489	−2.203	1.1
	(0.995)**	(0.969)**	
	(0.443)***	(0.502)***	

Sub-Industries

	Post-1997	Ave GDP share (%)
Services		
Professional and business services	−0.219	11.6
	(0.127)*	
	(0.098)**	
Educational services, health care, social assistance	−0.005	7.7
	(0.047)	
	(0.065)	
Other services, except government	−0.253	2.6
	(0.136)*	
	(0.103)**	
Food services and drinking places	−0.387	2.0
	(0.155)**	
	(0.148)***	
Arts, entertainment, and recreation	0.417	1.0
	(0.274)	
	(0.203)**	
Accommodation	0.025	0.9
	(0.270)	
	(0.359)	
Finance, insurance, real estate		
Real estate	−0.435	11.4
	(0.400)	
	(0.125)***	
Federal Reserve banks, credit intermediation, and related services	−0.254	3.6
	(0.463)	
	(0.354)	
Insurance, carriers and related activities	−1.299	2.6
	(0.631)**	
	(0.548)**	
Securities, commodity contracts, and investments	−0.287	1.3
	(0.531)	
	(0.337)	
Rental and leasing services, lessors of intangible assets	−0.030	1.3
	(0.244)	
	(0.290)	
Funds, trusts, and other financial vehicles	1.027	0.2
	(1.142)	
	(1.068)	

Regional analysis: Effects strong in South



Regional analysis: Effects strong in South

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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)

- Temp effects particularly strong in the South

Additional Results

Combining our estimates with climate projections

- Use monthly temperature projections for US for 2070-2099 (Girvetz et al., 2009)

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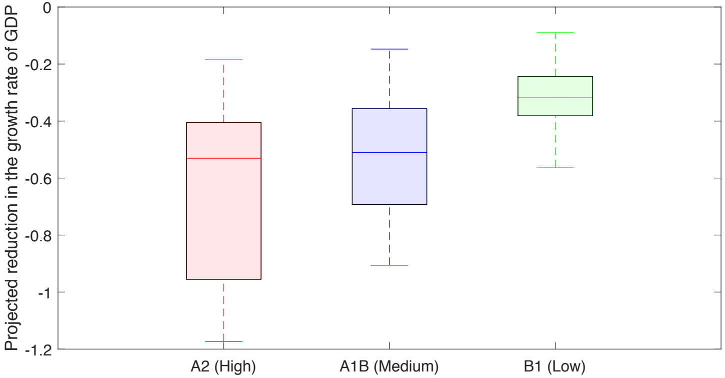
Projected GDP growth reduction, US 2070-99



Bottom and top lines denote the min and max projected impact.
Bottom and top of the rectangle denote 1st and 3rd quartile of the distribution of projected impacts.
Horizontal line is the median projected impact.

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- High emissions: reduction in GDP growth rate by up to 1.2 ppts $\rightarrow$ 33% of nominal growth rate

Robustness

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    - Spatial correlation
    - Controlling for precipitation
    - Controlling for temperature volatility
    - Excluding AR(1)
    - Excluding Alaska and Hawaii

Concluding Remarks

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- Finding: representative household willing to give up a lot of consumption for mitigation and adaptation

Setup

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

where

$$\begin{aligned} temp_t^{sum} &= 0.036 \cdot t + 0.0078 \cdot \varepsilon_t^{sum} \\ temp_t^{fall} &= 0.021 \cdot t + 0.0116 \cdot \varepsilon_t^{fall} \end{aligned}$$

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

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where

$$\begin{aligned} temp_t^{sum} &= 0.036\cdot(1-\Delta_m)\cdot t + 0.0078\cdot\varepsilon_t^{sum} \\ temp_t^{fall} &= 0.021\cdot(1-\Delta_m)\cdot t + 0.0116\cdot\varepsilon_t^{fall} \end{aligned}$$

- Welfare gains of
  1. Adaptation (Δ_a)
  2. Mitigation (Δ_m)

Welfare Analysis (cont'd)

Calculate the permanent changes in

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Calculate the permanent changes in

- Level of consumption (Δ_0)

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$$\underbrace{E_t\left[U\left(\{C_j\}_{j=t}^{\infty}\right)\right]}_{\text{business as usual}} = \underbrace{E_t\left[U\left(\left\{\widetilde{C}_j \cdot \exp\left(\Delta_0 + \Delta_1 \cdot j\right)\right\}_{j=t}^{\infty}\right)\right]}_{\text{intervention}}, \forall t.$$

Welfare Analysis: Results

Panel A: permanent reduction of the level (Δ_0)

		Δmitigation					
		0%	20%	40%	60%	80%	100%
Δadapt	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)

		Δmitigation					
		0%	20%	40%	60%	80%	100%
Δadapt	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
	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

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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
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$$\left.\begin{array}{lll} \boxed{\Delta_a} & 20\% & \textit{Adaptation} \\ \boxed{\Delta_m} & 00\% & \textit{Mitigation} \end{array}\right\}$$

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	100%	−14.0	−14.0	−14.0	−14.0	−14.0	−14.0

Give up:

$\boxed{\Delta_a}$ 20% *Adaptation*
$\boxed{\Delta_m}$ 00% *Mitigation*
$\Rightarrow$
0.10% of current consumption level
2.80% of current consumption growth

Welfare Analysis: Results

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		0%	20%	40%	60%	80%	100%
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Panel B: permanent growth rate reduction (Δ_1/μ_c)

		Δmitigation					
		0%	20%	40%	60%	80%	100%
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$$\left.\begin{array}{lll} \boxed{\Delta_a} & 60\% & \textit{Adaptation} \\ \boxed{\Delta_m} & 60\% & \textit{Mitigation} \end{array}\right\} \Rightarrow$$

Give up:

0.20% of current consumption level

11.8% of current consumption growth

	Winter	Spring	Summer	Fall
Alternative panel weights				
Time-varying GSP	0.008	−0.008	−0.148	0.105
	(0.051)	(0.067)	(0.077)*	(0.058)*
	(0.026)	(0.030)	(0.043)***	(0.042)**
State population	0.028	−0.025	−0.132	0.131
	(0.053)	(0.069)	(0.071)*	(0.061)**
	(0.025)	(0.039)	(0.039)***	(0.043)***
State area	0.018	0.012	−0.098	0.079
	(0.062)	(0.074)	(0.066)	(0.063)
	(0.033)	(0.045)	(0.054)*	(0.064)

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Alternative GSP measures

Per-capita GSP	-0.007	0.018	-0.119	0.098
	(0.047)	(0.068)	$(0.071)^{*}$	$(0.053)^{*}$
	(0.025)	(0.033)	$(0.049)^{**}$	$(0.040)^{**}$
Real GSP	-0.070	-0.016	-0.194	-0.006
	(0.043)	(0.081)	$(0.110)^{*}$	(0.068)
	$(0.040)^{*}$	(0.037)	$(0.087)^{**}$	(0.053)
Private industries only	0.013	0.010	-0.207	0.115
	(0.063)	(0.083)	$(0.087)^{**}$	$(0.069)^{*}$
	(0.029)	(0.041)	$(0.060)^{***}$	$(0.049)^{**}$

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Alternative definitions of seasons

Meteorological	0.026	−0.040	−0.083	0.025
	(0.043)	(0.053)	(0.074)	(0.055)
	(0.016)	(0.039)	(0.038)**	(0.033)
Core seasonal months	0.015	−0.026	−0.145	0.036
	(0.041)	(0.050)	(0.066)**	(0.050)
	(0.016)	(0.024)	(0.033)***	(0.027)

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Alternative temperature data

Temp. weighted by pop.	0.012	−0.004	−0.129	0.094
	(0.048)	(0.066)	(0.074)*	(0.057)*
	(0.023)	(0.029)	(0.041)***	(0.034)***
Pre-1950 deseasonalization	0.000	0.003	−0.154	0.102
	(0.049)	(0.065)	(0.072)**	(0.055)*
	(0.025)	(0.032)	(0.047)***	(0.040)**
Non-deseasonalized gridded temp.	0.001	−0.005	−0.167	0.100
	(0.042)	(0.057)	(0.064)***	(0.047)**
	(0.023)	(0.028)	(0.047)***	(0.035)***

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	Winter	Spring	Summer	Fall
Other				
Spatial correlation	0.011	−0.020	−0.109	0.024
	(0.046)	(0.061)	(0.066)*	(0.058)
Controlling for precipitation	0.003	0.008	−0.169	0.093
	(0.047)	(0.069)	(0.077)**	(0.056)*
	(0.025)	(0.039)	(0.048)***	(0.037)**
Controlling for temp. vol.	−0.009	−0.013	−0.138	0.106
	(0.050)	(0.062)	(0.071)*	(0.055)*
	(0.024)	(0.030)	(0.042)***	(0.040)***
Excluding AR(1)	0.023	0.014	−0.156	0.086
	(0.052)	(0.073)	(0.080)*	(0.059)
	(0.029)	(0.039)	(0.054)***	(0.036)**
Excluding Alaska and Hawaii	−0.001	0.000	−0.153	0.118
	(0.048)	(0.065)	(0.071)**	(0.056)**
	(0.026)	(0.032)	(0.048)***	(0.040)***

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Productivity and Employment

	Winter	Spring	Summer	Fall
Productivity	−0.033	−0.020	−0.152	0.132
	(0.067)	(0.065)	(0.087)*	(0.048)***
	(0.042)	(0.031)	(0.050)***	(0.054)**
Employment	0.013	−0.086	0.008	−0.021
	(0.032)	(0.051)*	(0.059)	(0.042)
	(0.015)	(0.051)*	(0.037)	(0.019)

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