# Riding the Waves: Inequality and Adaptation to Extreme Temperatures in a Changing Climate

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OIGI Conference
October 5, 2023

# Income Heterogeneity and the Welfare Costs of Climate Change

Effects of climate change could vary across households

- Households differ in space $\Rightarrow$ different exposure to climate damage
- Households differ in income $\Rightarrow$ different abilities to adapt

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- Abstract from all heterogeneity (e.g., Acemoglu et al. (2012), Golosov et al. (2014), Barrage (2020))
- Focus on spatial heterogeneity (e.g., Balboni (2021), Carleton et al. (2022), Nath (2022), Rudik et al. (2022), Cruz and Rossi-Hansberg (forthcoming))

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## This paper: focus on income heterogenity

- Direct effects of higher temperatures in the US
- Framework: heterogeneous agent model + temperature and adaptation

# Main Findings: Income Heterogeneity Matters

Welfare impacts of climate change vary across income groups

- High income HHs: welfare impacts near zero
- Middle income HHs: benefit in cold regions, hurt in hot regions
- Low income HHs: hurt in cold regions, benefit in hot regions

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## Heterogeneity matters for aggregate outcomes

- Macro lit: welfare cost of business cycles, inflation, asset pricing, etc.
- This paper: welfare cost of climate change

# Literature

## Empirical studies on distributional effects of changes in temperature

- Doremus, Jacqz, and Johnston (2022); Hsiang et al. (2017); Beher et al (2021); Park et al. (2018); Park and Stainer (2021)

## Global models of optimal climate policy with within-region inequality

- Belfiori and Macera (2022); Kornek et al. (2021); Dennig et al. (2015)

## Distributional effects of carbon pricing

- Parry (2004); Fullerton and Heutal (2007); Metcalf (2007); Chiroleu-Assoline and Fodha (2014); Parry and Williams (2010); Williams et. al (2015); Cole et al. (2018); Fried, Novan, and Peterman (2018, 2023); Jacobs and Van Der Ploeg (2019)

# Simple Model

# Simple Model

- Purpose: examine distributional impacts of changes in temperature
- Lot of simplifying assumptions for tractability
- Relaxed later in quantitative model

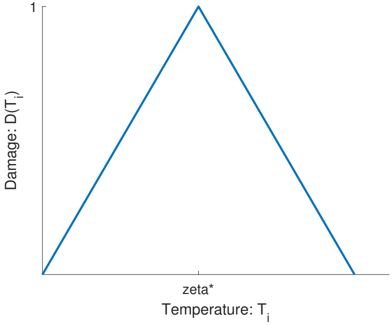
# Household

## Utility

$$u_i = \begin{cases} G(\zeta)\left[\ln(c_i) + \ln\left(D(T_i)h_i\right)\right] & : \underline{\zeta} \le T_i \le \overline{\zeta} \\ -\Theta & : \text{otherwise} \end{cases}$$

## Damage

$$D(T_i) = \begin{cases} \frac{T_i}{\zeta^\star} & : 0 \le T_i \le \zeta^\star \\ \frac{2\zeta^\star - T_i}{\zeta^\star} & : \zeta^\star < T_i \le 2\zeta^\star \end{cases}$$



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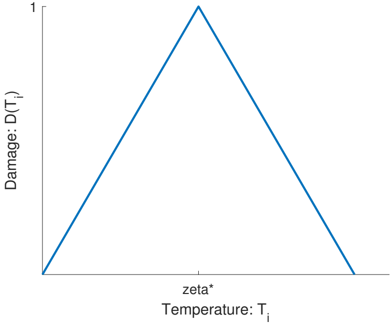


## Indoor temperature

$$T_i = \zeta + e_i^h - e_i^c$$

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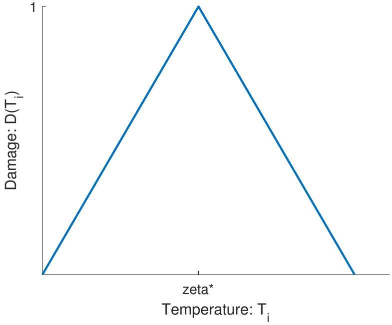



## Indoor temperature

$$T_i = \zeta + e_i^h - e_i^c$$

## Budget constraint

$$y_i = c_i + p^h h_i + p^{ec} e_i^c + p^{eh} e_i^h$$

# Interior Solution for $\zeta < \zeta^\star$

Optimal choices of consumption, housing, and temperature

$$c_i^\star = \frac{y_i + p^{eh}\zeta}{3}, \qquad h_i^\star = \frac{y_i + p^{eh}\zeta}{3p^h} \qquad T_i^\star = \frac{y_i + p^{eh}\zeta}{3p^{eh}}$$

Optimal choices of heating and cooling energy

$$e_i^{h^\star} = T_i^\star - \zeta \qquad e_i^{c^\star} = 0$$

Outdoor temperature acts as a "transfer from nature"

- All HHs receive $\zeta$ degrees of heating for free, augmenting income by $p^{eh}\zeta$

# Distributional Effects of $\downarrow$ Outdoor Temperature: Intuition

- Transfer is a larger share of lower income households' budgets
- $\Rightarrow$ decrease in transfers from a colder day is regressive
- In general: extreme temperatures are more costly for lower income HHs
- $\Rightarrow$ climate change is regressive iff it leads to more extreme temperatures

# Quantitative Model

# Quantitative Model

- Same intuition as the simple model
- Adds
  - Heating and cooling capital
  - Full distribution of temperature
  - Dynamic heterogeneous agent model
- Subtracts
  - Amenity value
  - Mortality

# Overview

## 5 regions

- Differ by temperature distribution (e.g., cold, cool, mild, warm, hot)

## Within each region

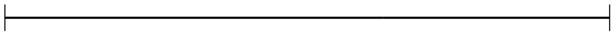
- Continuum of heterogeneous households
  - Draw labor productivity shocks
  - Choose consumption, savings, housing, heating and cooling capital, energy
- Continuum of perfectly competitive firms
  - Produce final good, housing, heating and cooling capital, energy

## Federal government

- Taxes households
- Provides energy assistance

# Temperature Distribution

- 100 possible outdoor temperatures



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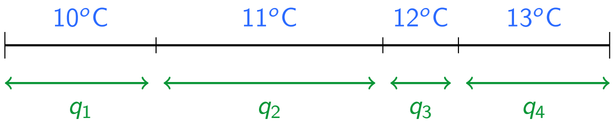

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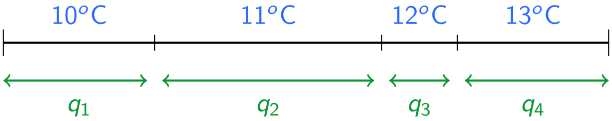
- Uncertainty over the distribution



# Household: Utility

$$u_{in} = \sum_{j=1}^{J} q_{ijn} \left[ \frac{{c_{ijn}}^{1-\sigma}}{1-\sigma} + \psi \frac{(D(T_{ijn})h_{in})^{1-\sigma}}{1-\sigma} \right], \quad D(T_{ijn}) = \frac{1}{1+\chi(T_{ijn}-\zeta^{\star})^2}$$

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- $D(T_{ijn}) \in [0, 1]$: damage from being too hot or too cold
- Damage depends on difference between temperature and bliss point

# Household: Indoor Temperature

$$T_{ijn} = \zeta_j + \frac{1}{h_{in}^{\gamma}} \left[ \underbrace{A^h (x_{in}^h)^{\theta^h} (e_{ijn}^h)^{\eta^h}}_{\text{production of heating}} - \underbrace{A^c (x_{in}^c)^{\theta^c} (e_{ijn}^c)^{\eta^c}}_{\text{production of cooling}} \right]$$

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- $\zeta_j$: outdoor temperature
- Produce heating and cooling from capital, $x$, and energy $e$
    - Fixed cost of heating and cooling capital
    - Estimate $\theta$'s and $\eta$'s: data on heater and AC prices, capacity, and efficiency
    - Calibrate $A^h$ and $A^c$ to match heating and cooling energy budget shares

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- $h^\gamma$: bigger houses require more energy and capital to heat and cool
  - Calibrate $\gamma$ to match variation in energy expenditures with income

# Household: Timing and Optimization

- Period starts
- Labor productivity shock realizes
- Choose housing, heating, and cooling capital
- Temperature distribution realizes
- Choose consumption, heating and cooling energy, and indoor temperature in each sub-period

# Household Optimization

$$V(a_{in};\nu_{in}) =$$

$$\max_{h_{in},x^h_{in},x^c_{in}} \mathbb{E}\left\{ max_{\{e^h_{ijn},e^c_{ijn},c_{ijn}\}_{j=1}^J}\left[\sum_{j=1}^J q_{ijn}\left(\frac{c_{ijn}^{1-\sigma}}{1-\sigma}+\psi\frac{(D(T_{ijn})h_{in})^{1-\sigma}}{1-\sigma}\right)+\beta\mathbb{E}V(a'_{in};\nu'_{in})\right]\right\}$$

subject to the budget constraint:

$$(1-\tau)wz_{in}+(1+r)a_{in}+B_{in}=$$

$$\sum_{j=1}^J q_{ijn}(c_{ijn}+p^{eh}e^h_{ijn}+p^{ec}e^c_{ijn})+p^h h_{in}+p^{xh}x^h_{in}+p^{xc}x^c_{in}+\Omega^h\mathbf{1}_{x^h>0}+\Omega^c\mathbf{1}_{x^c>0}+a'_{in}$$

# Calibration

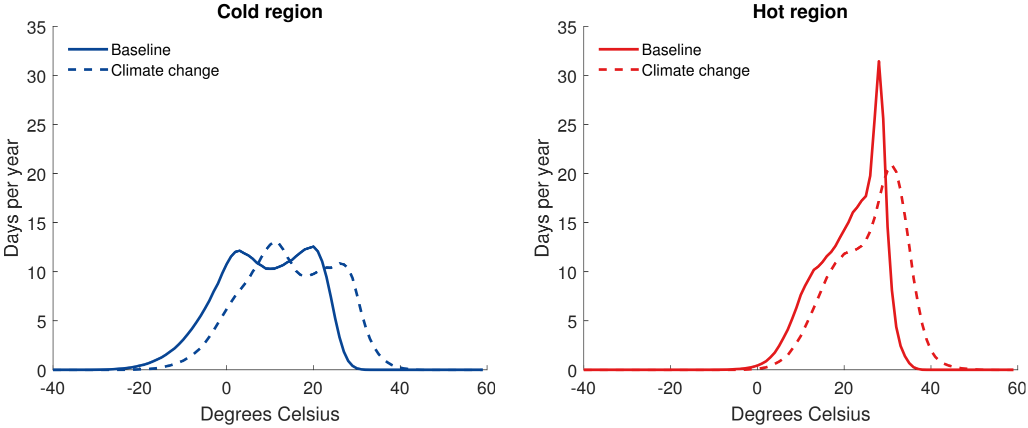
# Quantitative Experiments

# Experiment: Distributional Impacts of Climate Change

Compare two equilibria

1. No-climate-change equilibrium with current temperature distribution
2. Climate-change equilibrium with a new temperature distribution

# Temperature Distribution w/ and w/o Climate Change



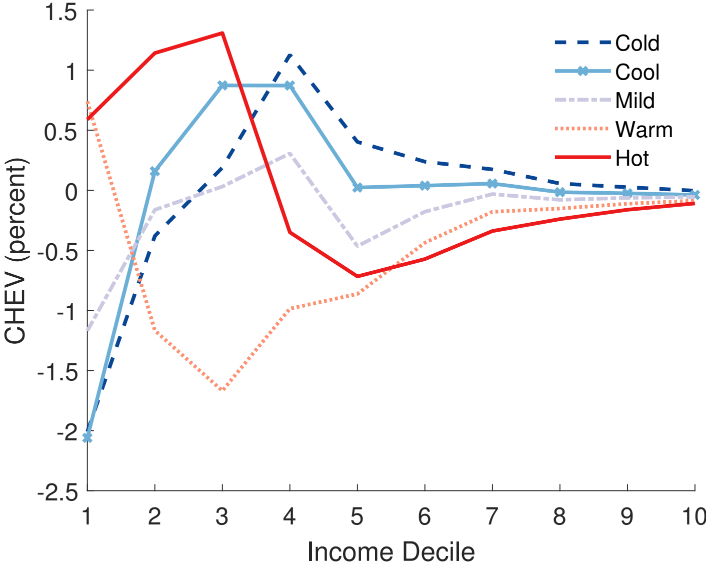

- County-level projections of 2100 temperature distribution under RCP 8.5 (Rasmussen et al. 2016)

# Welfare Measure

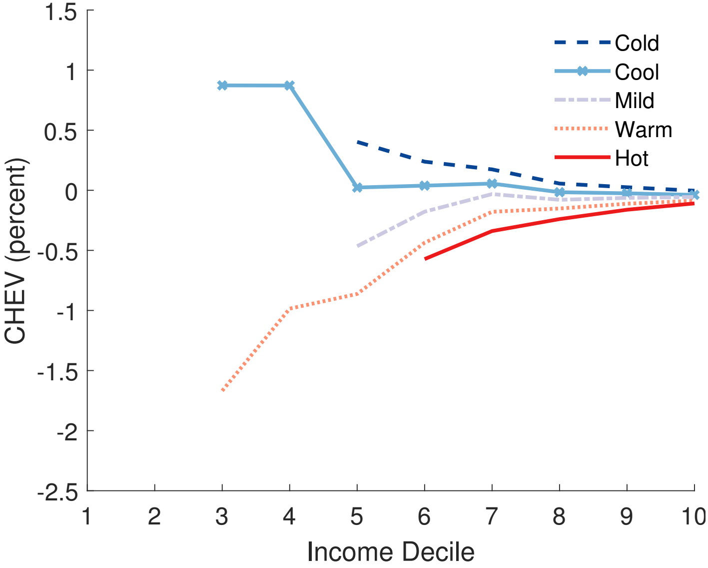
## Consumption-housing equivalent variation

*Percent increase in consumption and housing a household would need in every period in the no-climate-change equilibrium, in expectation, so that they are indifferent between the no-climate-change and climate-change equilibrium*

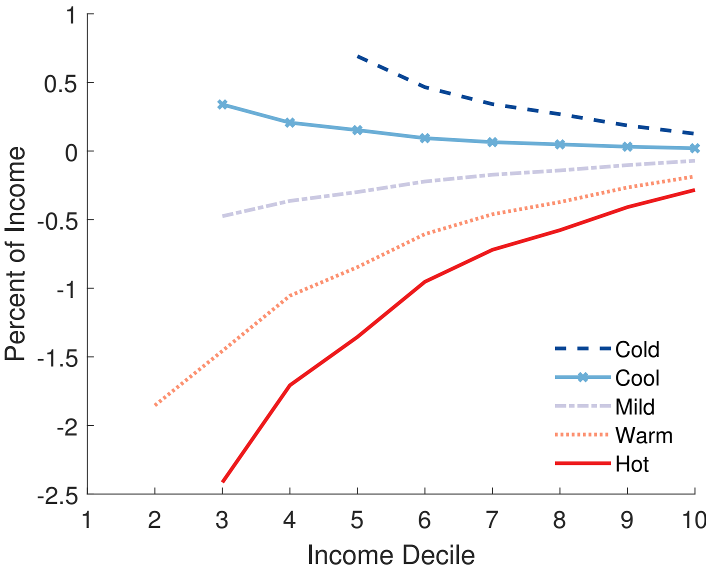
# Welfare Impacts of Climate Change



# Welfare Impacts of Climate Change: Middle and High Income



# Why? (1) Changes in Transfers from Nature Relative to Income



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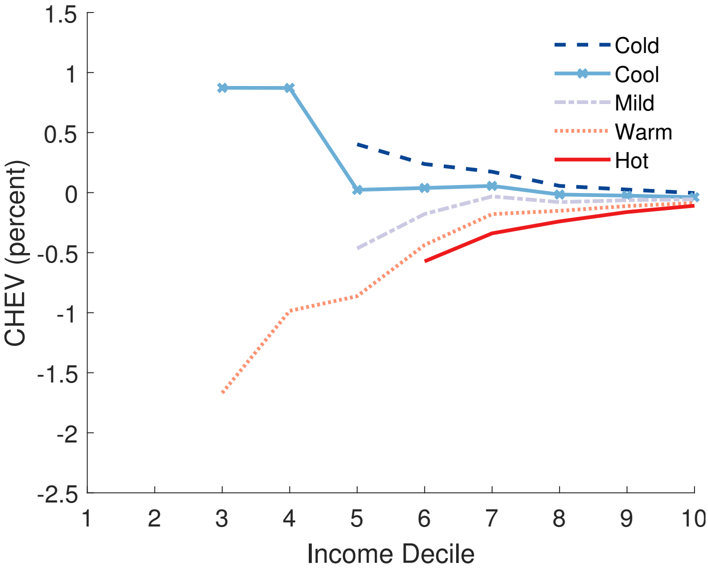

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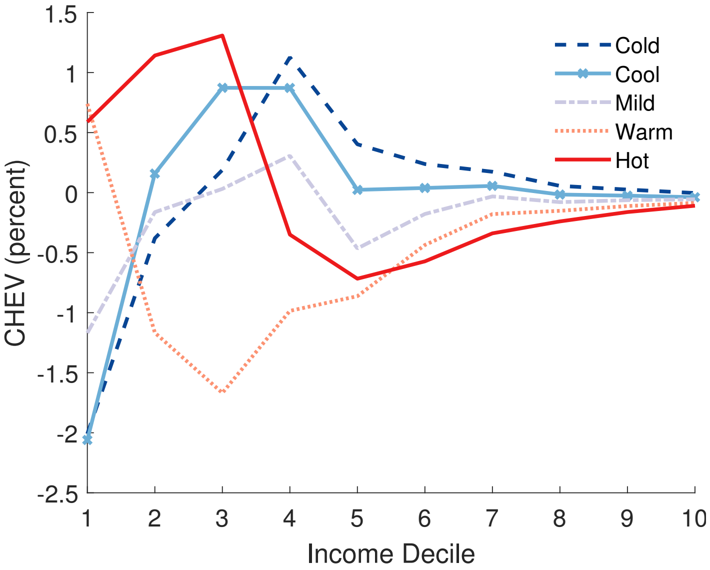
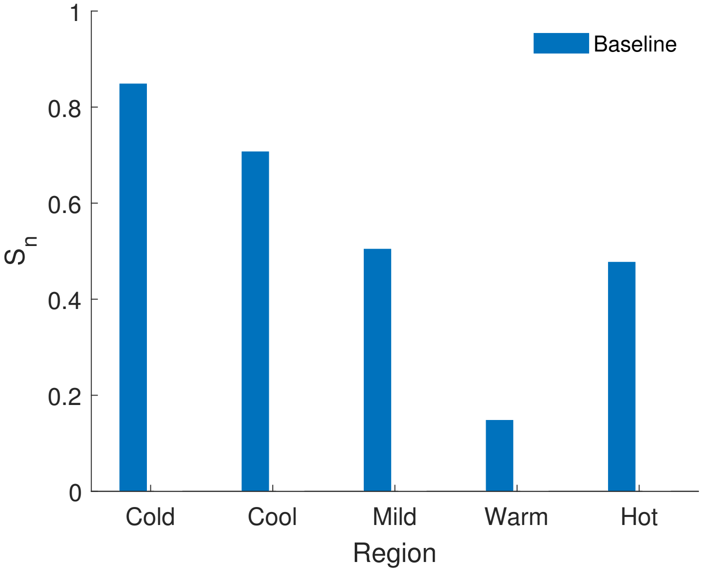


# Why? (2) Changes in Specialization



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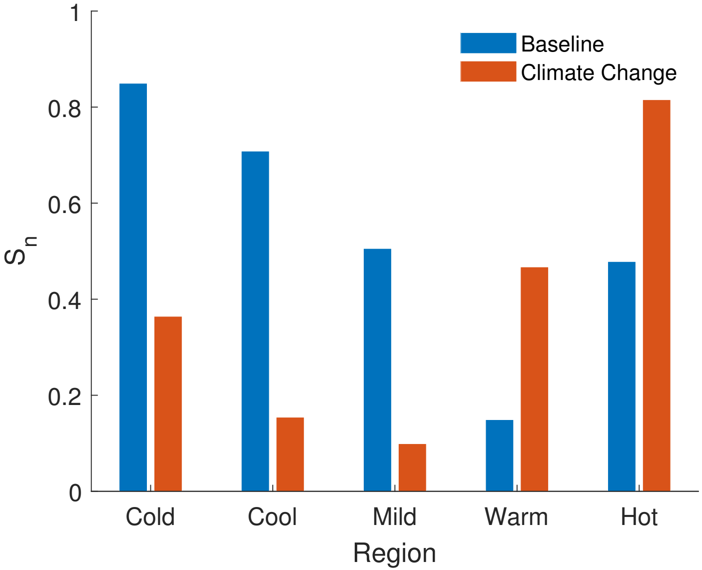
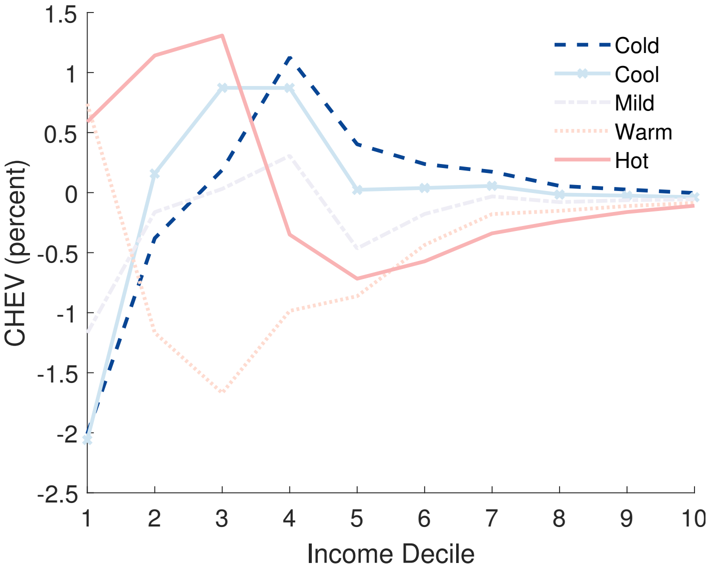
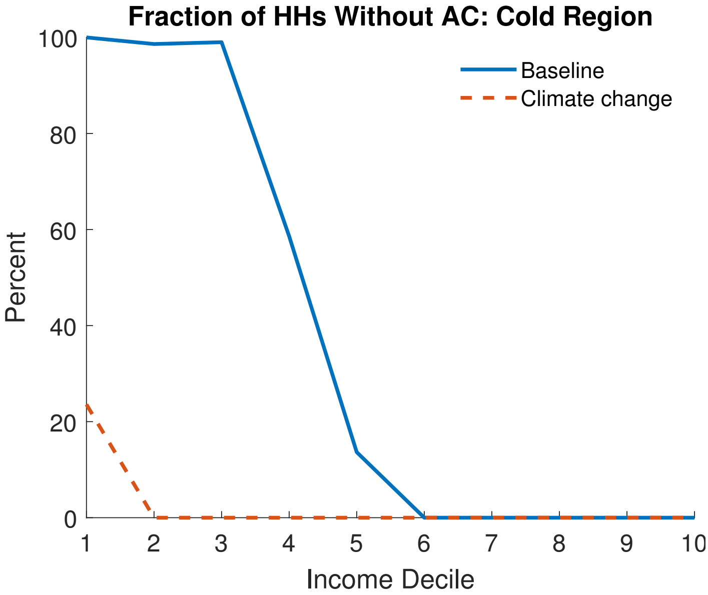


# Welfare Impacts of Climate Change: Cold Region



# Cold Region: Complete Specialization

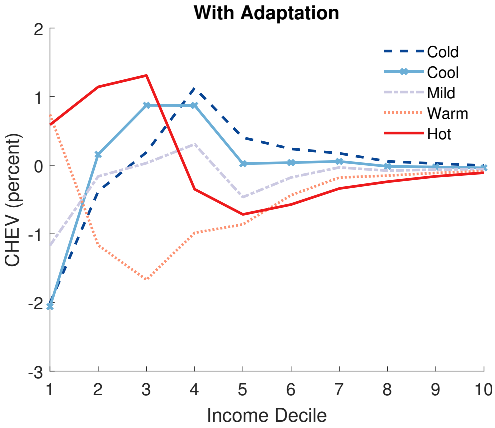


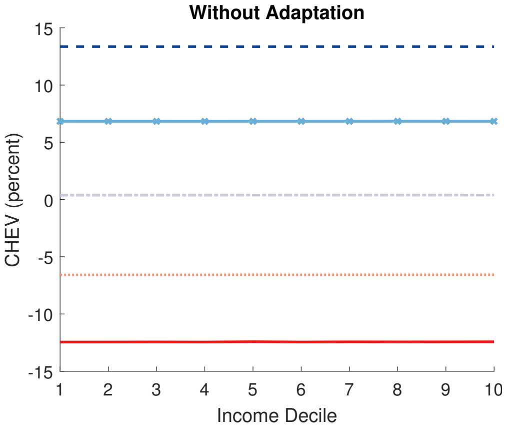
# Experiment: Role of Adaptation to Temperature

HHs cannot adapt to temperature: indoor temperature = outdoor temperature

1. No-climate-change equilibrium
2. Climate-change equilibrium

# Effect of Adaptation on the Welfare Costs of Climate Change




- Welfare effects vary with income because of adaptation

# Experiment: Importance of Income Heterogeneity

Halve the variance in the labor productivity shock

1. No-climate-change equilibrium
2. Climate-change equilibrium

# Income Heterogeneity Matters for Aggregate Welfare Cost

Welfare Impact of Climate Change (CHEV, percent)

| | Cold | Cool | Mild | Warm | Hot |
|---|---|---|---|---|---|
| Baseline simulation | -0.65 | -0.54 | -0.50 | -0.53 | 0.52 |
| Low variance simulation | -0.51 | -0.37 | -0.49 | -0.45 | 0.35 |

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## Channels

- Lower variance $\downarrow$ the range of incomes, particularly important at the bottom
- Lower variance $\uparrow$ the number of HHs in corner solutions $\Rightarrow \uparrow$ the importance of changes in specialization favorability

# Conclusion

Income heterogeneity matters for the welfare impacts of climate change

- Welfare effects of climate change vary across income groups
  - Changes in transfers from nature
  - Changes in specialization favorability

- Heterogenous impacts are driven by changes in adaptation

- Income heterogeneity is important for understanding aggregate welfare costs of climate change

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Thank you!