Cooling Inequality on a Hotter Planet

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July, 2024

Outline

- Cooling inequality in the background of climate change
- Define and quantify the inequality
  - Using nationwide household-level data in China
  - Lower-income HHs: less carbon footprint, insufficient cooling consumption $\rightarrow$ more vulnerable to heat exposure
- Simulation
  - Wealth effect (+): wealthier HHs are more responsive to heat exposure $\rightarrow$ gap $\uparrow$
  - Forced consumption effect (-): As temperatures rise, all households have to consume more cooling $\rightarrow$ gap $\downarrow$
  - Empirical results: changes in this inequality vary across different climate change scenarios
- Policy implications
  - Trade-off between equality and carbon emission

Motivation: Why cooling consumption matters?

- ACs: adaptation tool + contributor to climate change
  - Basic for health: lack of cooling can increase mortality (Carleton et al., 2022; Luber and McGeehin, 2008) hospitalizations for multiple diseases (Ebi et al., 2021; Ostro et al., 2010; Thompson et al., 2018) , reduce cognitive performance (Thompson et al., 2018) students' academic performance (Ebi et al., 2021)→AC usage could alleviate these problems
  - Energy intensive: contributing to over 10% of global greenhouse gas emissions (Dong et al., 2021)
- Exploring the inequality in responsibility and adaptation → justify subsidies

Related literature and our contributions

- Mitigating climate change
  - A detailed survey at the household level $\rightarrow$ high-quality data
  - Constructing a Household Carbon Footprint (HCF) index attributed to cooling
- HH adaptations to climate change
  - Defining cooling inequality $\rightarrow$ justify subsidies
  - Quantifying the equality-pollution dilemma
- AC purchase and usage behavior
  - Investigating the response pattern in China

Data

- AC usage and HHs' characteristics
  - Chinese Residential Energy Consumption Survey, conducted by RUC[1]
  - 5 intensive rounds, 8 years, sample size of 20,000+
  - Includes almost all provinces[2]
- Weather information
  - Global Surface Summary of the Day (GSOD)
  - Daily station-level data $\rightarrow$ daily-city level data

[1] CRECS2012-2014 available on: http://crecs.ruc.edu.cn/jj/gyCRECS/index.htm, CRECS2017 available on: http://cgss.ruc.edu.cn/

[2] except for the Xizang Autonomous Region

AC usage behaviors

- AC penetration rate (extensive margin)
- The number of AC units owned (extensive margin)
- The energy consumption attributed to AC usage (intensive margin)
  - $\Sigma_i \text{cooling time}_i * \text{power of AC}_i$
  - $\rightarrow$ mitigate potential biases caused by respondents' memory

Heat exposure indicator

- Cooling degree days (CDD)
  - $CDD = \sum_{T \geq T_0} (T - T_0)$, T_0 is set to 18.3°C (Sailor, 2003).
  - A few robustness checks
    - ⋆ change reference point
    - ⋆ culmulative CDD

HH carbon footprint (HCF)

- A Streamlined Life Cycle Assessment (SLCA) approach
- Direct HCF and indirect HCF (Wang et al., 2022; Zhang et al., 2020)
  - Direct HCF: $direct\_HCF_i = f\_grid_p \cdot Energy_i$
    - f_grid_p: Emission factor in province p[3]
    - $Energy_i$: the energy consumption attributed to AC usage in HH i
  - Indirect HCF:
    $indirect\_HCF_i = N_i \cdot HCF\_production + ratio\_refrigerant \cdot direct\_HCF_i$
    - $N_i \cdot HCF$: number of ACs in HH i*HCF when producing per AC[4]
    - $ratio\_refrigerant \cdot direct\_HCF_i$: HCF by refrigerant leakage[5]
  - Total HCF: $total\_HCF_i = direct\_HCF_i + indirect\_HCF_i$

[3] China Regional Power Grids Carbon Dioxide Emission Factors (2023), a report issued by the Chinese Academy of Environmental Planning

[4] =0.173 tCO2 (Sun et al., 2014)

[5] ratio=44.3% (Dong et al., 2021)

Stylized facts: wealthier HHs produce more HCF

- Income per cap ↑ HCF ↑

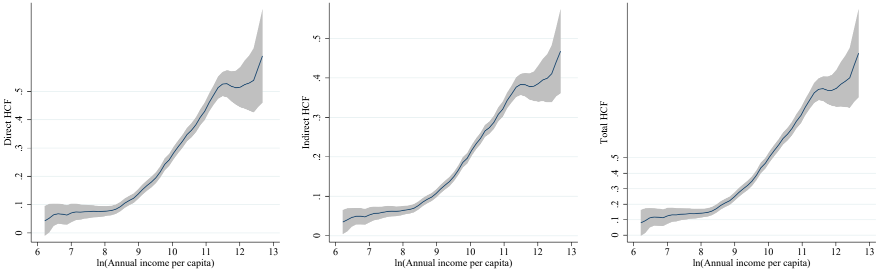


Figure 1: Kuznets curves of HCF

Stylized facts: lower-income HHs consume less cooling

- Income per cap ↑ cooling ↑

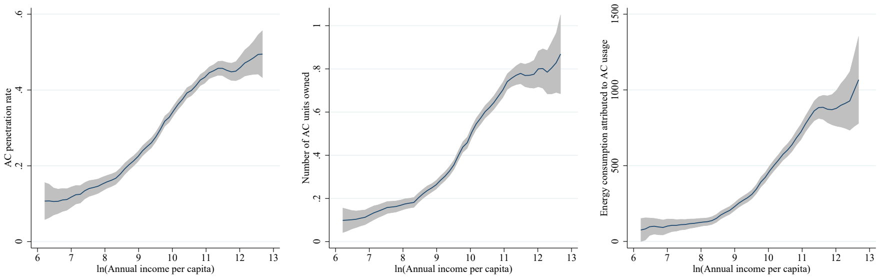
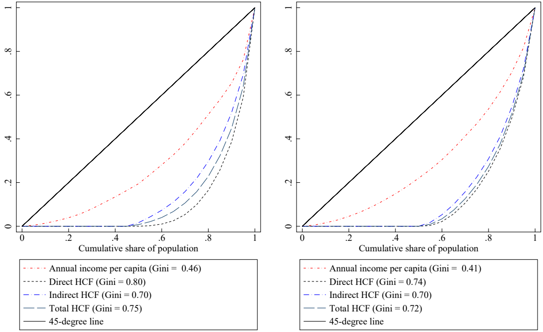


Figure 2: Engel curves of AC usage behaviors

Lorenz curves and Gini index of HCF

- Lorenz curves and Gini index of cooling (Jacobson et al., 2005; Wu et al., 2017)
  - HCF inequality > income inequality
  - Direct HCF inequality > indirect HCF inequality
  - Slightly decreases from 2012 to 2020

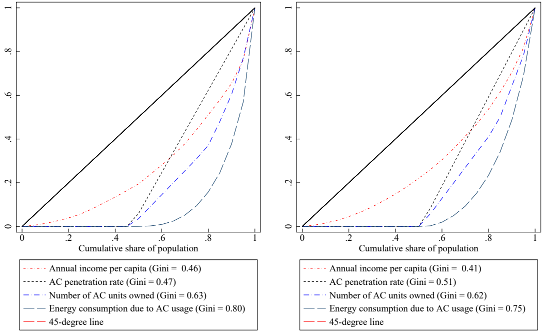


Panel (a): 2012 Panel (b): 2020

Figure 3: Lorenz curves of Household Carbon Footprint (HCF)

Lorenz curves and Gini index of cooling

- Cooling inequality > income inequality
- Intensive margin inequality > Extensive margin inequality
- Slightly decreases from 2012 to 2020



Panel (a): 2012 Panel (b): 2020

Figure 4: Lorenz curves of Air Conditioner (AC) usage behaviors

Decomposition of the inequality

- AC energy consumption attributed to AC usage: within-group inequality: 84%
- Total Household Carbon Footprint (HCF): within-group inequality: 97%

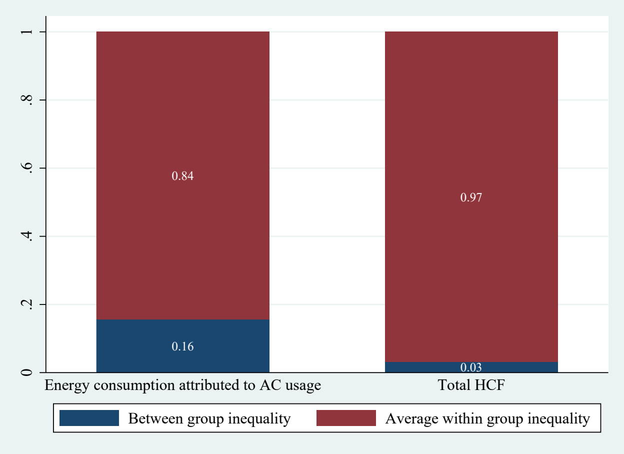


Figure 5: decomposition of the inequality between the northern and southern China

Baseline: specification

- $AC_{ict} = \beta_0 + \beta_1 CDD_{ict} + \beta_2 \mathbf{1}[HighIncome_{ict}] + \mathbf{X}_{ict}\gamma + \delta_p + \mu_t + \epsilon_{ict}$
- $AC_{ict} = \beta_0 + \beta_1 CDD_{ict} + \beta_2 \mathbf{1}[HighIncome_{ict}] + \beta_3 CDD_{ict} \times \mathbf{1}[HighIncome_{ict}] + \mathbf{X}_{ict}\gamma + \delta_p + \mu_t + \epsilon_{ict}$
  - AC_{ict}: AC usage behaviors, include
    - ★ AC penetration rate
    - ★ Number of AC units owned
    - ★ Energy consumption due to AC usage
  - CDD_{ict}: Cooling Degree Days, an indicator of heat exposure
  - $1[HighIncome_{ict}]$: whether HH i belongs to higher-income group[6]
  - X_{ict}: household characteristics and meteorological factors
  - δ_p: province fixed effects
  - μ_t: year fixed effects
  - ε_{ict}: error term
  - Adjusted using sampling weights
  - Standard errors clustered at province level
- Weather condition exogenous $\rightarrow$ Causal effect

[6] i.e. whether has an income higher than the median income level

Baseline: lower-income HHs less responsive

Table 2. Responses of AC usage behaviors to heat exposure.

	(1)	(2)	(3)	(4)	(5)	(6)
	AC penetration rate		Number of AC units owned		Energy consumption	
	Baseline	Interaction	Baseline	Interaction	Baseline	Interaction
CDD×High_income		0.0001**		0.0002***		0.3711***
		(0.000)		(0.000)		(0.081)
CDD	0.0003*	0.0002	0.0006*	0.0005*	1.7549**	1.5458**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.744)	(0.703)
High_income	0.0807***	0.0175	0.1871***	0.0080	227.7765***	-158.0037**
	(0.009)	(0.034)	(0.024)	(0.056)	(32.922)	(68.277)
Constant	-0.0959	-0.1034	1.1441	1.1064	3,077.2632	3,031.8432
	(0.540)	(0.538)	(1.149)	(1.145)	(1,925.628)	(1,884.940)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Province fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19,630	19,630	18,905	18,905	19,631	19,631
R-squared	0.253	0.254	0.243	0.245	0.156	0.159

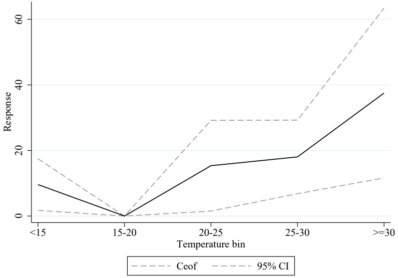
Next Possible concerns

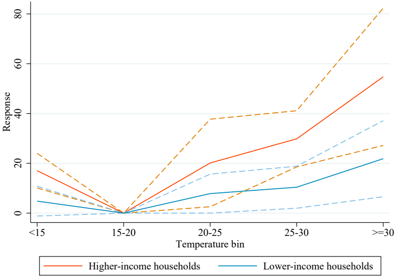
Possible concerns

- **Considering the energy efficiency of ACs**
  - Lower-income households tend to use cheaper and less energy-efficient ACs?
  - Calculate the actual cooling capacity using the power input and the Energy Efficiency Ratio (EER) of each AC unit
  - The Gini index for cooling capacity is smaller than that for AC energy consumption
  - Lower-income households, which can afford ACs later, tend to purchase more efficient ACs due to technological advancements
- **Considering the insulation of the house**
  - Lower-income households might live in homes with poorer insulation?
  - Underestimate of the inequality
- **Considering alternative cooling methods**
  - Higher-income households may spend more time away from their residences (e.g., taking more vacations)→underestimate of the inequality
  - Lower-income households might use cooling services in public areas: endure heat exposure while traveling to and from these places + spend time on the road + these areas are closed during the night

A more flexible specification: response curve

- $AC\ Energy_{ict} = \sum_{j=1}^{J} \beta_j Temp_{j,ct} + \mathbf{1}[HighIncome_{ict}] + \mathbf{X}_{ict}\gamma + \delta_p + \mu_t + \epsilon_{ict}$
  - $Temp_{j,ct}$: number of days where the temperature fell within the bin[7]
- Consistent with the U-shaped response curve found in the literature
- The response gap exists across all temperature bins





Panel (a): Full sample　　Panel (b): By income group

Figure 6: Response curves of AC energy use on temperature

[7] 15-20 °C as baseline

Response curve: international comparison

- The US
  - The gap only appears at extremely high temperatures (Doremus et al., 2022)
  - Mainly explained by the lack of liquidity
- China
  - Systematic gap across all temperature ranges
  - With higher savings rates and lower subsidized energy prices, it is easier to smooth out such shocks
  - Suggests a long-term cost-saving motivation

Simulation: Method

- Simulate future cooling inequality condition
- the direction of inequality change is determined by the relative size of these effects:
  - Wealth effect (+): wealthier HHs are more responsive to heat exposure $\rightarrow$ gap $\uparrow$
  - Forced consumption effect (-): As temperatures rise, all households have to consume more cooling $\rightarrow$ gap $\downarrow$
    - ⋆ e.g.2,4$\rightarrow$4,6
- The climate change scenarios and corresponding projected Cooling Degree Day (CDD) data
  - World Bank Group's Climate Change Knowledge Portal
  - Four scenarios： SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5， Larger numbers indicate a more passive prediction of climate change

Simulation results

- Scenario SSP1-2.6: steady trend (the two effects are about the same size)
- Three other scenarios: decreasing trend (the forced consumption effect dominates)

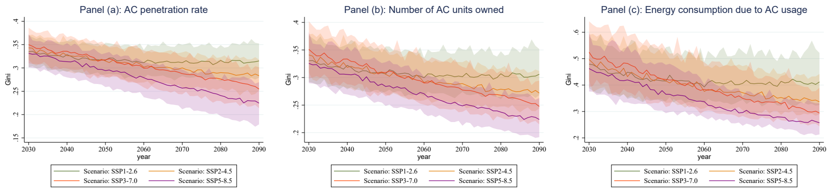


Figure 7: Simulated Gini index of Air Conditioner (AC) usage behaviors

Equity-pollution dilemma? Literature

- Empirical findings on this hypothesis are diverse
  - yes: carbon neutrality increases urban-rural inequality(Jia et al., 2022) urbanization increases residential energy use(Xie et al., 2020) income redistribution contributing to increased carbon emissions(Sager, 2019)
  - No: reverse causation relations between energy poverty and income inequality （Nguyen and Nasir, 2021） the development of rural areas alleviating both energy poverty and inequality simultaneously （Ma et al., 2021） increase in income reducing biomass consumption （Zhang et al., 2023; Zou and Luo, 2019）

Yes, equity-pollution dilemma exists

- Environmental Engel curves (EECs)
- Carbon EECs are upward-sloping and concave
- This concavity suggests an "equity-pollution dilemma"—progressive income redistribution may raise aggregate emissions from consumption

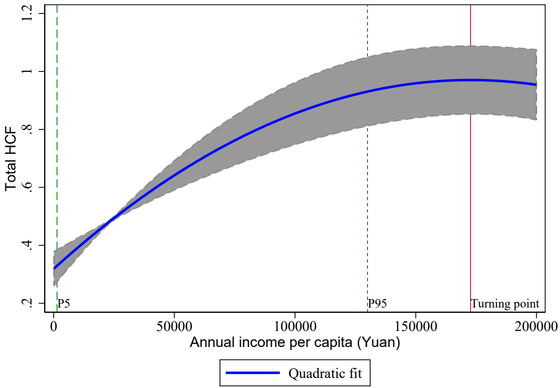


Figure 8: Environmental Engel curves (EECs)

Quantifying the dilemma

- We assume a policy in which two households are randomly chosen, and the richer household j conducts a marginal transfer to the other household i
- result in a change in Household Carbon Footprint (HCF) of: $\frac{\partial y_i}{\partial m_i} - \frac{\partial y_j}{\partial m_j} = \beta_2(m_j - m_i)$
- Calculating the expectation
  - $E_{ij}(\frac{\partial y_i}{\partial m_i} - \frac{\partial y_j}{\partial m_j}|m_j > m_i) = -2\hat{\beta}_2 E_{ij}(m_j - m_i|m_j > m_i) = -2\hat{\beta}_2\Phi(F(m))$
  - $where \Phi(F(m)) = \int\int|y - z|dF(y)dF(z)$
- if the richer household j transfer 1000 yuan to the poorer one, it would cause a 1.71kg CO2 increase in the total HCF.
- This corresponds to 12.2% of the average HCF that a 1000 yuan income can bring

Simulation: the dilemma may not persist

- The forced consumption effect dominates $\rightarrow$ inequality $\downarrow$ $\rightarrow$ the concavity of the Environmental Engel Curves (EEC) $\downarrow$ $\rightarrow$ magnitude of the dilemma$\downarrow$

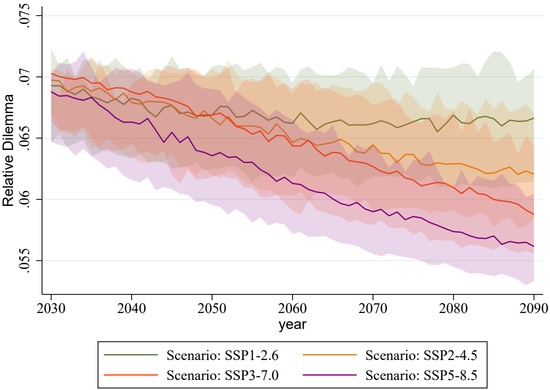


Figure 9: Simulated relative magnitude of the equity-pollution dilemma

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