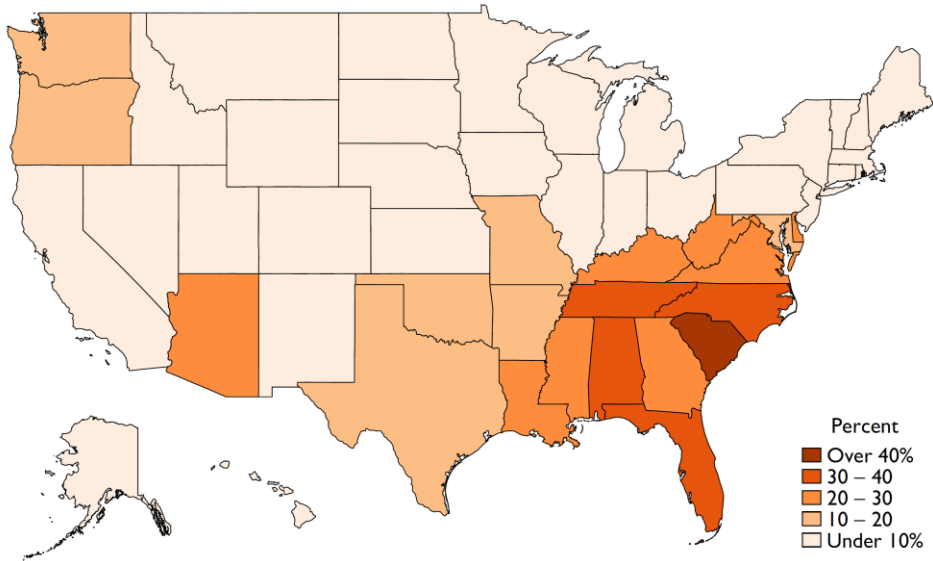


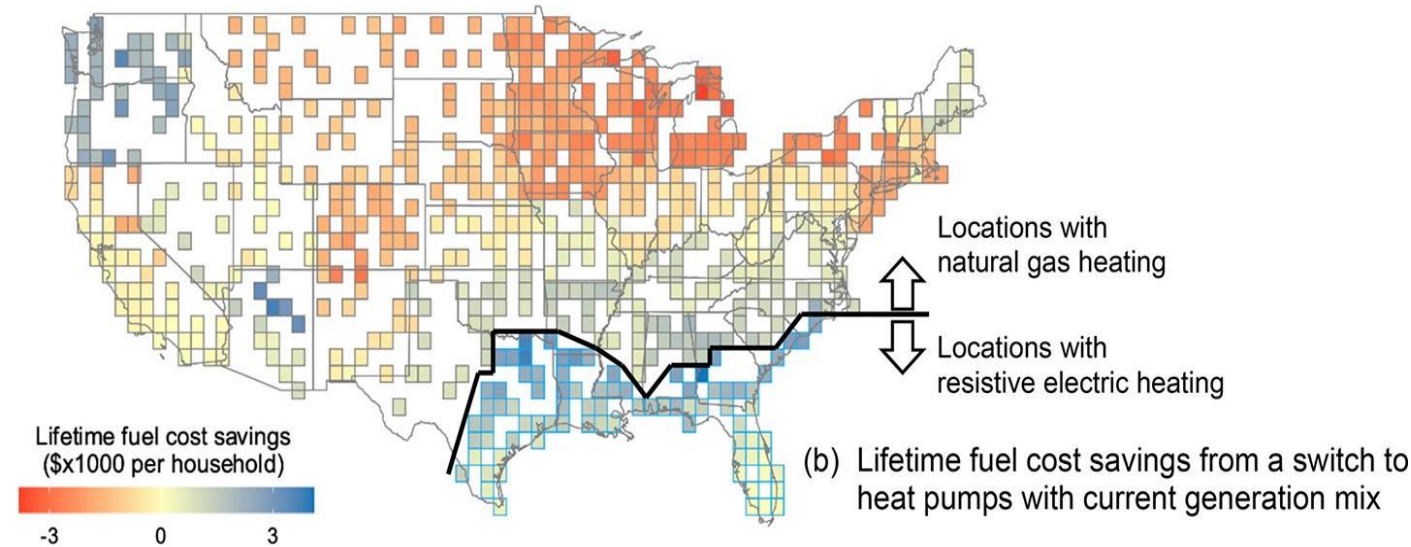
What matters for the racial disparity in clean heating technology adoption? Evidence from U.S. heat pumps

Xingchi Shen

The distribution of heat pumps and private benefits



Heat pump adoption
Source: Davis 2023



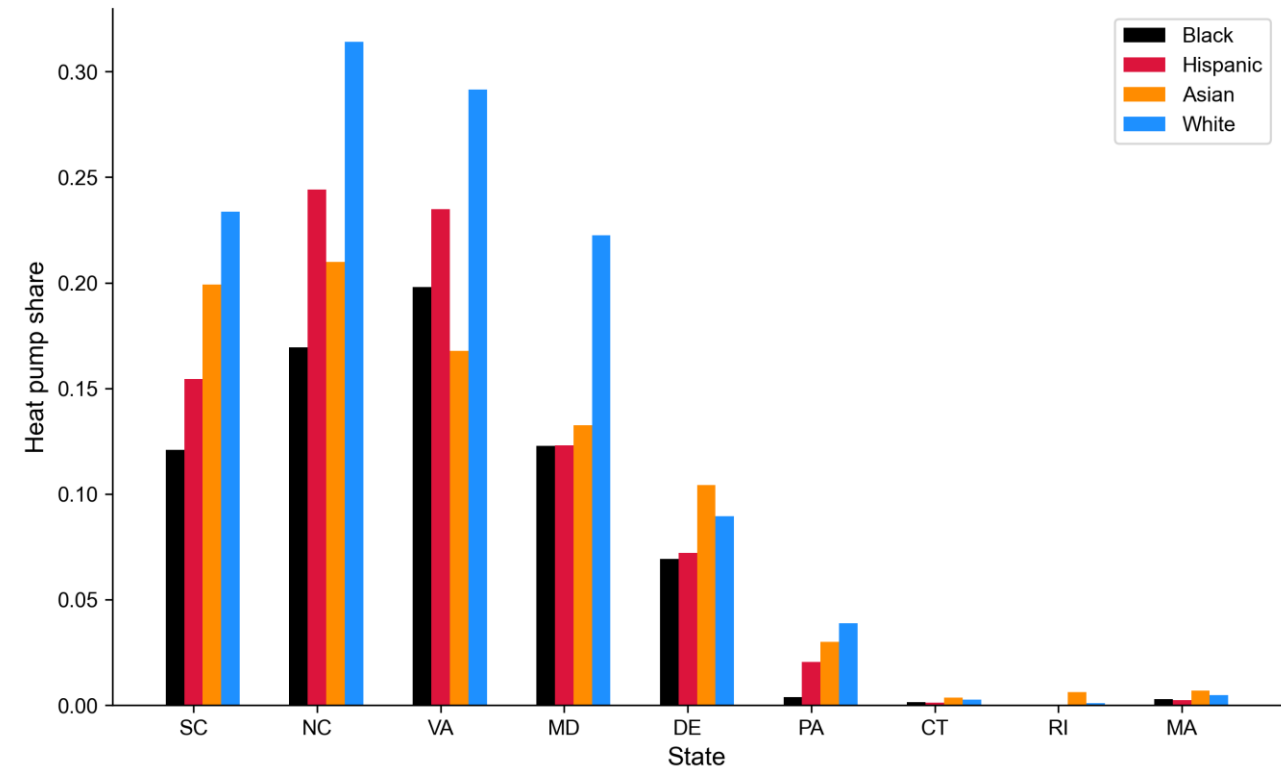
Air source heat pump lifetime fuel cost savings
Source: Vaishnav & Fatimah, 2020

Minority people install fewer heat pumps

- Minority groups installed much fewer heat pumps disproportionately in the U.S. (Edwards et al. 2023).
- Few studies have explored the underlying reasons for racial disparity in the adoption of heat pumps.

Research questions:

- What is the distribution of racial inequality in the adoption of air source heat pumps?
- What can explain the racial inequality?
- Why do minority groups have less access to air source heat pumps?



Heat pump adoption share by race.
Data source: CoreLogic & DataAxle, 2021

Decomposing the drivers of racial inequality

Data

- Household property data 2009 -2021 (CoreLogic)
 - Address, building structure, building and land size, year built, and heating and cooling equipment, among other features
- Household demographic data 2021 (DataAxle)
 - Address, income, wealth, purchasing power, age of the household head, number of children, homeownership, ethnicity
- Education levels of individuals 2021 (L2)
- Public data
 - HDD and CDD from NOAA, Sales and revenues of electric utilities from EIA 861, Natural gas price from EIA, Utility service territory from HIFLD, Energy efficiency incentives from DSIRE & websites, Yale Program on Climate Change Communication

Road map

1. Measure the racial gap in heat pump adoption in a standardized way at the ZIP code level.
2. Review the factors related to heat pump adoption based on a model of energy efficiency investment.
3. Construct the covariates related to heat pump adoption at the ZIP code level based on the theoretical model.
4. A two-step data-driven approach to decompose the drivers:
 - Machine learning - LASSO
 - Shapley Value regression - to decompose R-square

Outcome - heat pump adoption racial inequality

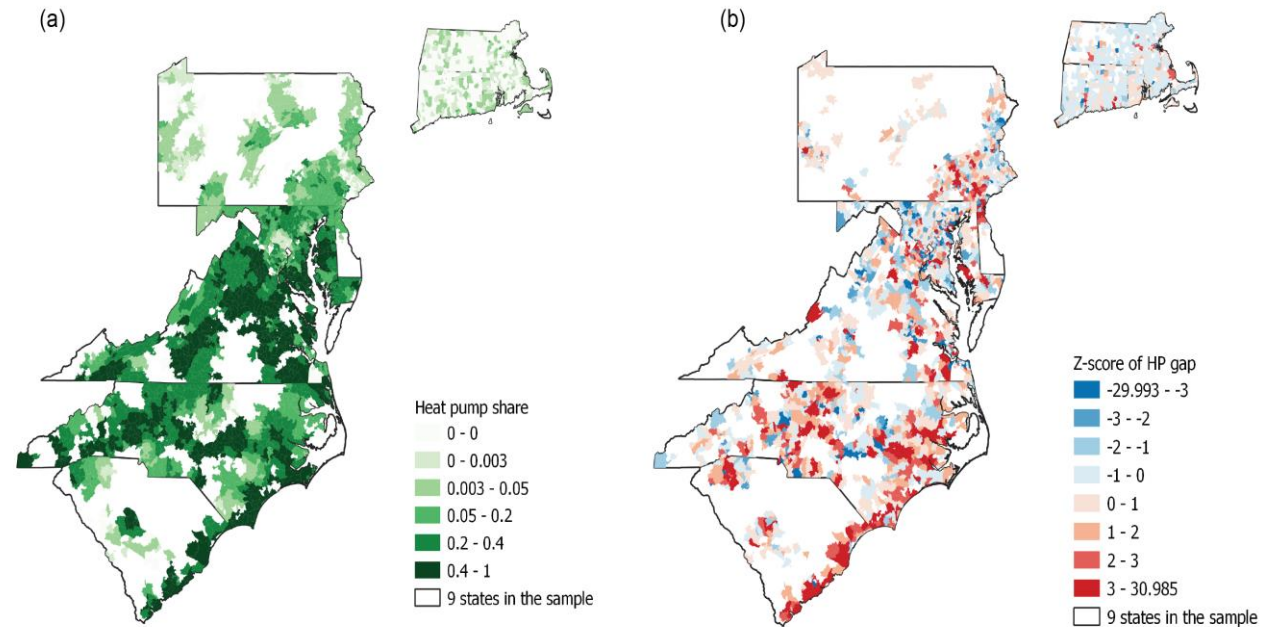
Measurement – Z score

- To measure the heat pump adoption gap in a standardized way, I borrow the idea from the Z statistic test commonly used to test the difference between two binomial distributions.

$$Z\text{-score} = \frac{p_w - p_m}{\sqrt{\hat{p}(1 - \hat{p}) \left(\frac{1}{n_w} + \frac{1}{n_m} \right)}}$$

- The minority households in this analysis refers to Hispanic and Black households.

Distribution of heat pumps and racial inequality



13 million households in SC NC VA MD DE PA CT RI MA

Covariates

Model of energy efficiency investment

- When deciding between a heat pump and a classical HVAC system, a rational and time-consistent agent would opt for the heat pump if and only if:

$$\underbrace{u(P_h - P_c)}_{\text{initial costs}} < \underbrace{\sum_{t=1}^T [\delta^t \cdot u(\sigma_{ct} - \sigma_{ht})]}_{\text{fuel savings}} + \underbrace{u(\tau_h)}_{\text{warm glow}}$$

- Minority groups install fewer heat pumps:

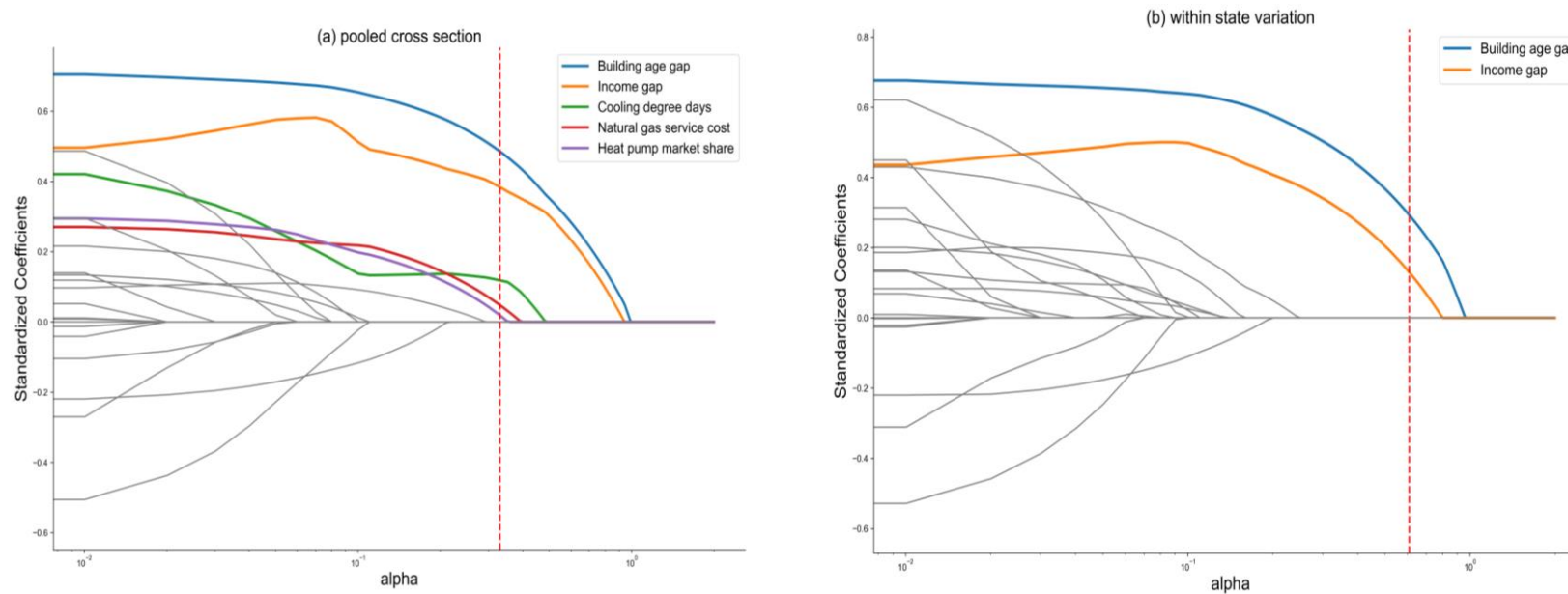
$$\frac{1}{N^w} \sum_{i=1}^{N^w} \mathbb{1}\{WTP_i^w > P_{h,i}^w\} > \frac{1}{N^m} \sum_{i=1}^{N^m} \mathbb{1}\{WTP_i^m > P_{h,i}^m\}$$

Observed covariates

- Initial installation costs:
 - Average and racial gap of building attributes (year built, total living area, and housing type), education level and gap, $\sum_{t=1}^{10} rebate_{t,z}$, $\sum_{t=1}^{10} loan_{t,z}$
- Fuel savings:
 - Average HDD and CDD for past decade, average electricity and natural gas price for past decade, utility natural gas access, homeownership level and gap
- Discount rates:
 - Income and wealth levels and gaps, $\sum_{t=1}^{10} loan_{t,z}$
- “Warm glow” effects:
 - Education level and gap
 - Opinion about climate change

Two-step data-driven approach

Model selection – Lasso



R-square decomposition – Shapley Value

| | Pooled cross section | | Within state variation | |
|--------------------------|-----------------------|--------------------|------------------------|--------------------|
| | (1) Lasso | (2) R^2 share | (3) Lasso | (4) R^2 share |
| Year built gap | 0.7772*** (0.1377) | 0.43 | 0.6328*** (0.1429) | 0.57 |
| Income gap | 0.5765*** (0.1227) | 0.35 | 0.6855*** (0.1286) | 0.43 |
| CLDD | 0.1883** (0.0738) | 0.08 | | |
| Natural gas price/access | 0.2868*** (0.0555) | 0.08 | | |
| Heat pump market share | 0.2834*** (0.0711) | 0.06 | | |
| State FE | No | | Yes | |
| R-squared | 0.1804 | | 0.1396 | |
| Number of observations | 2,351 | | 2,353 | |

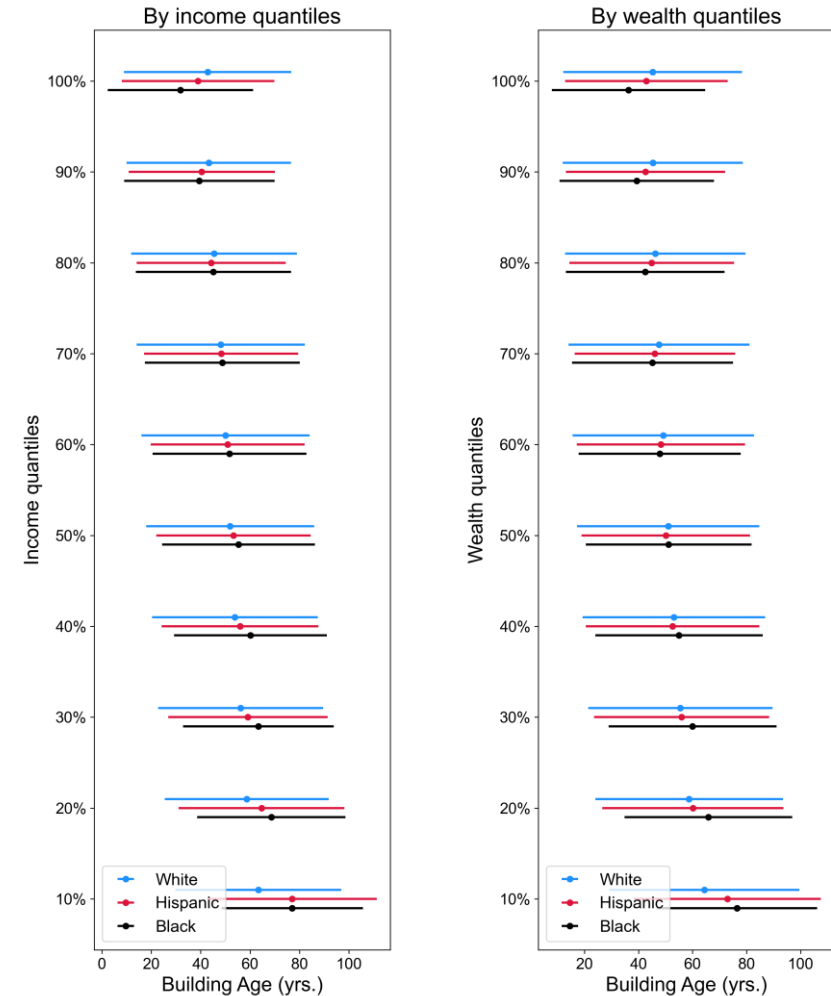
Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The racial gap in building age persists after conditioning on income

Low-income and low-wealth Black and Hispanic populations are more likely to own older buildings compared to low-income and low-wealth White populations.

Historical or ongoing discriminatory housing market:

- Redlining (Swope et al. 2022)
- Zoning policies (Ellickson 2022)
- Steering (Galster 1990; Christensen and Timmins 2018)
- Intergenerational wealth accumulation (Shapiro et al. 2013)
- and others.



Causal evidence: impact of temperature on racial inequality

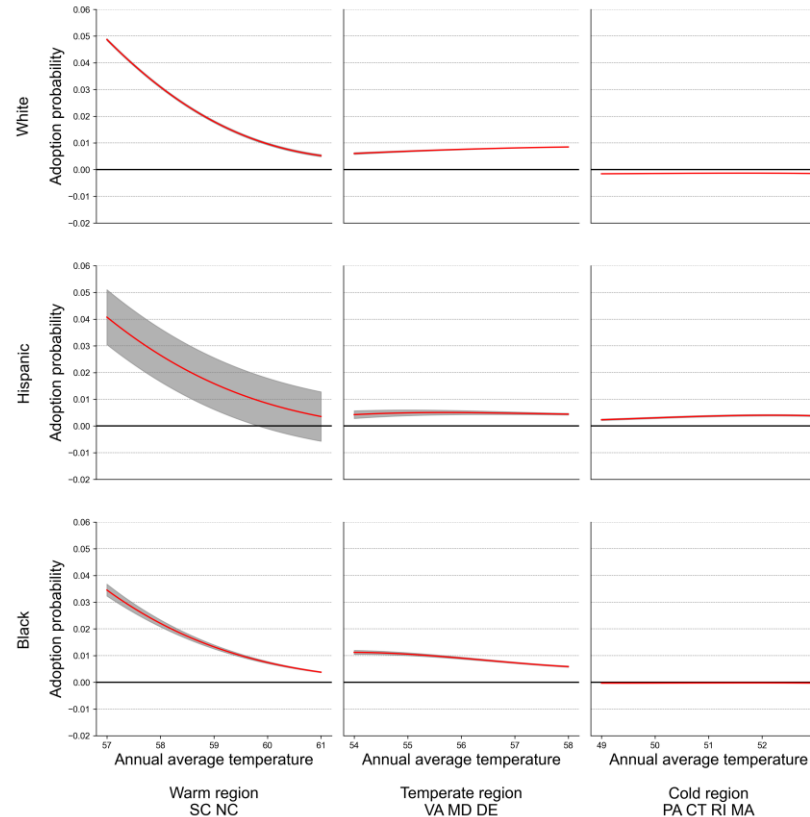
Identification

I construct a panel data at the individual household level, covering the years from 2010 to 2021. A linear probability model is employed:

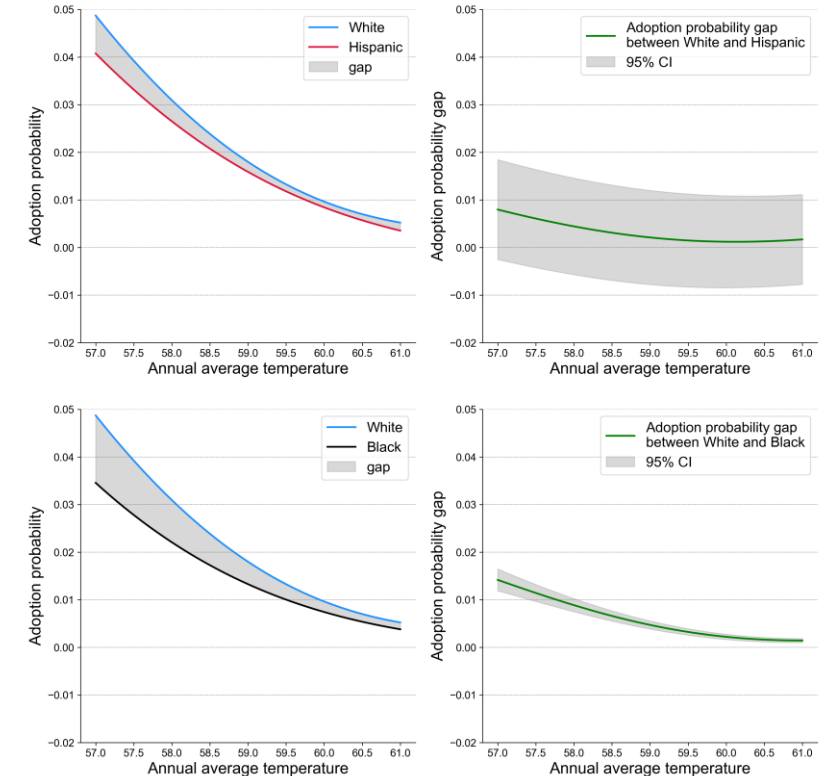
$$\Delta Y_{ijst} = g(T_{it}, R_j, C_s) + Elec_{it} + \alpha_{st} + \delta_i + \epsilon_{ijst}$$

- Y_{ijst} is dummy indicating heat pump adoption status of households
- T_{it} , fourth-order polynomials of annual average temperature
- R_j , the racial identity
- C_s , the climate regions

Impacts by race and region



Racial gap in warm region



Causal evidence: impact of natural gas price on racial inequality

Identification

- A panel dataset is constructed including households located within natural gas utility service territories in SC, NC, VA, MD, and DE covering the years 2010-2021.

- A LPM model is employed:

$$\Delta Y_{ijst} = \beta \log(Ng_{st}) + Elec_{it} + HDD_{it} + CDD_{it} + \alpha_t + \delta_i + \epsilon_{ijst}$$

with $j = \{\text{White, Hispanic, Black}\}$

- The difference in coefficients between different racial groups can be interpreted as the change in the heat pump adoption gap resulting from a one percent increase in natural gas prices.

Impacts by race

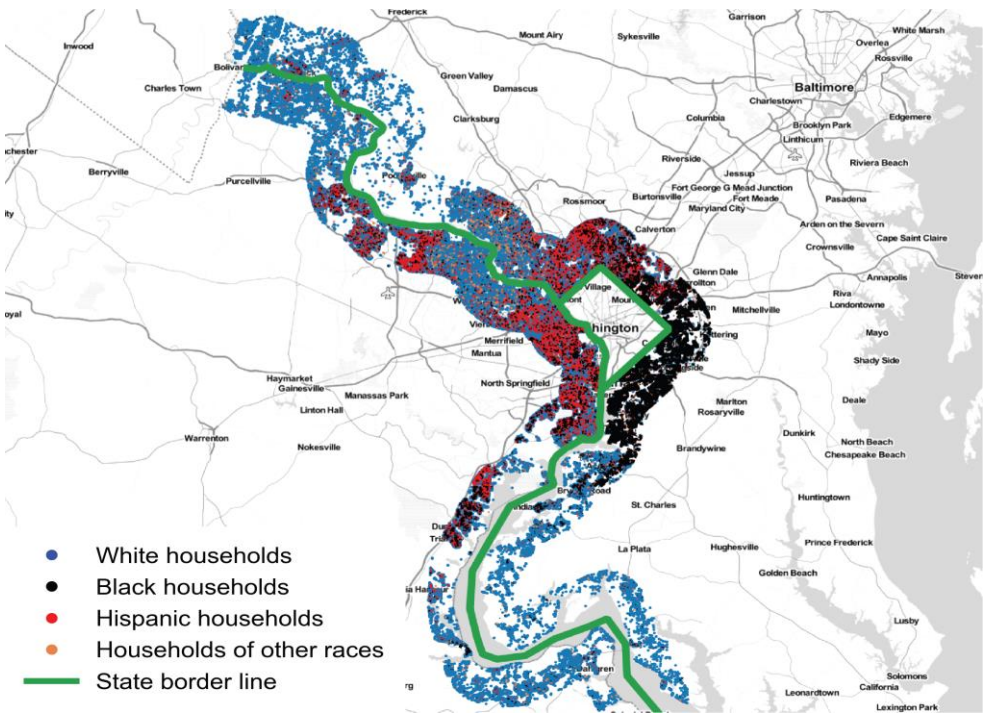
| | (1) All | (2) White | (3) Hispanic | (4) Black |
|-------------------------------|----------------------|----------------------|----------------------|----------------------|
| log(natural gas price) | 0.015*** (0.0003) | 0.018*** (0.0003) | 0.011*** (0.0009) | 0.003*** (0.0008) |
| 4th polynomials of elec price | Yes | Yes | Yes | Yes |
| 4th polynomials of HDD | Yes | Yes | Yes | Yes |
| 4th polynomials of CDD | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes |
| Household FE | Yes | Yes | Yes | Yes |
| R-squared | 0.0087 | 0.0096 | 0.0049 | 0.005 |
| Number of observations | 41,296,249 | 33,046,818 | 2,714,485 | 5,534,946 |
| Number of households | 5,148,441 | 4,157,366 | 328,996 | 662,079 |

Note: *** p<0.01, ** p<0.05, * p<0.1.

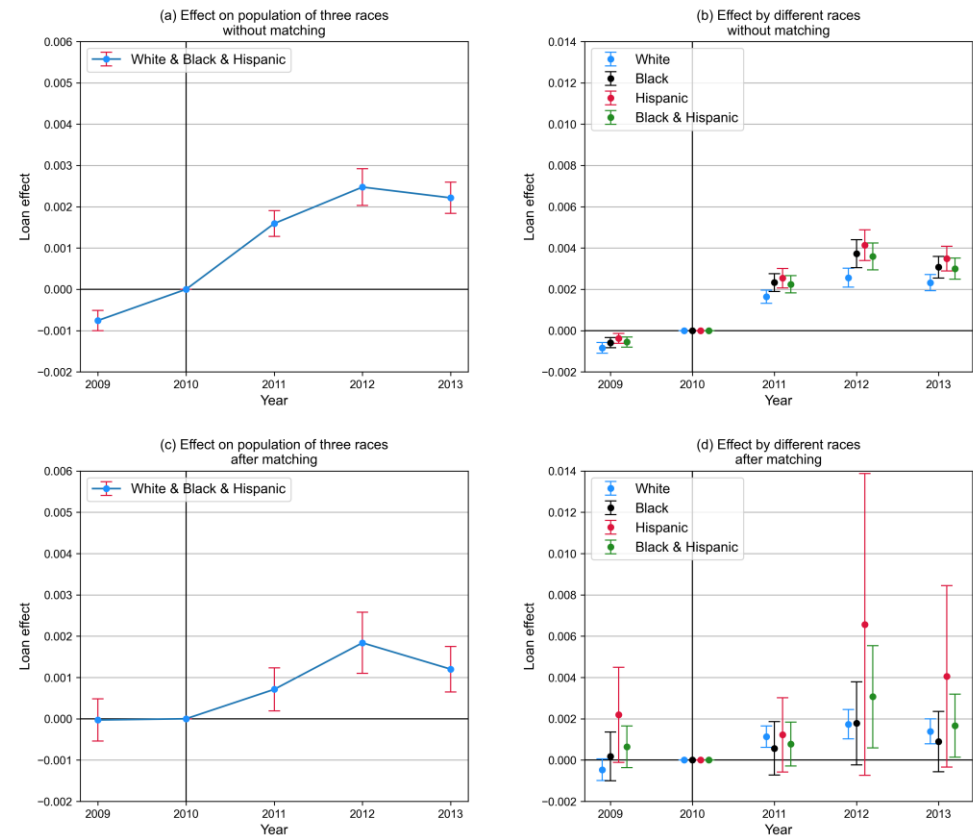
Impact of loan program on racial inequality

Be SMART financing program in MD

Identification – Difference in differences



Event study – effects by race

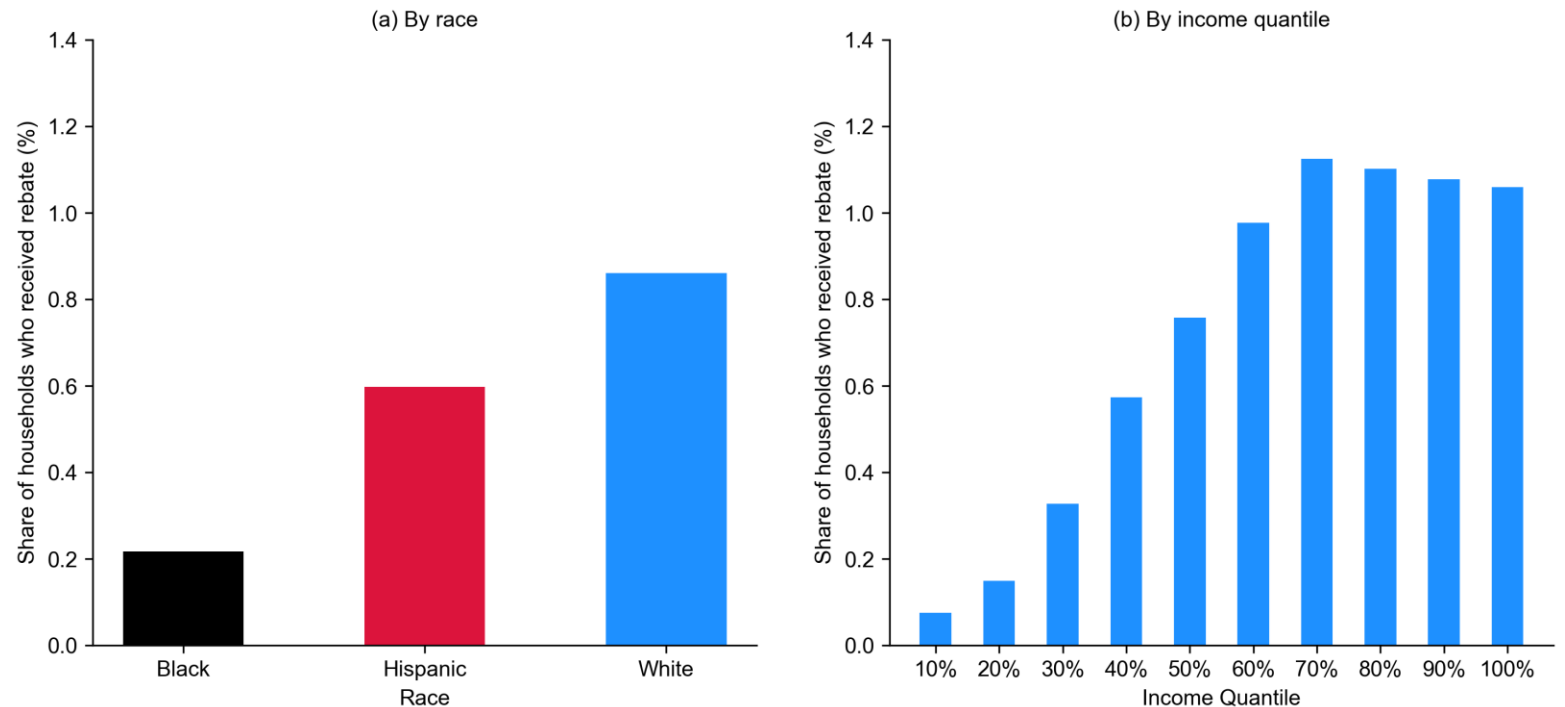


Racial inequality in access to rebate programs

MA Clean Energy Center rebate program

- Rebate amount was about \$600 per ton, and the total amount paid was 28 million dollars between 2014 and 2019.
- I match rebate recipients' address with household demographic data sourced from DataAxle.
- The program was designed to give higher rebate amounts per installed heat pump to low income.

The share of households who received rebate 2014-2019, MA



Policy implications

Enact more targeted policy interventions that promote building retrofits, particularly in older structures where low-income minority populations are disproportionately represented.

The climate change and increase in natural gas prices (e.g., carbon pricing, outright ban) can amplify the racial disparity in heat pump adoption.

Low-interest loan programs can offer a lower public budget burden while also having the potential to alleviate the racial gap.

Thank you!