

What Matters for Electrification?

Evidence from 70 Years of U.S. Home Heating Choices

Lucas Davis

University of California, Berkeley

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Motivation

U.S. households burn vast amounts of fossil fuels on-site each year for space heating.

- 2.7 trillion cubic feet of natural gas
- 2.9 billion gallons of heating oil
- 2.5 billion gallons of propane

The carbon dioxide equivalent of having 40 million cars on the road.

Policymakers Increasingly Interested in Electrification

Climate Adaptation

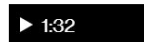
San Francisco Bans Natural Gas Use in New Buildings

By [Mark Chediak](#)

November 11, 2020, 10:17 AM PST *Updated on November 11, 2020, 2:29 PM PST*

- ▶ Measure is strictest of its kind for large California cities
- ▶ All-electric construction required for buildings starting 2021

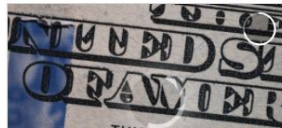
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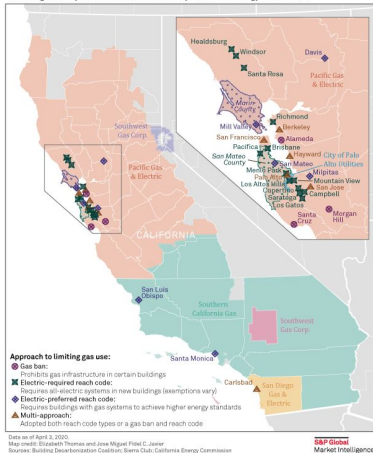


San Francisco will ban the use of natural gas in new buildings starting next year, becoming the latest city in California to clamp down on the heating and cooking fuel because of climate concerns.

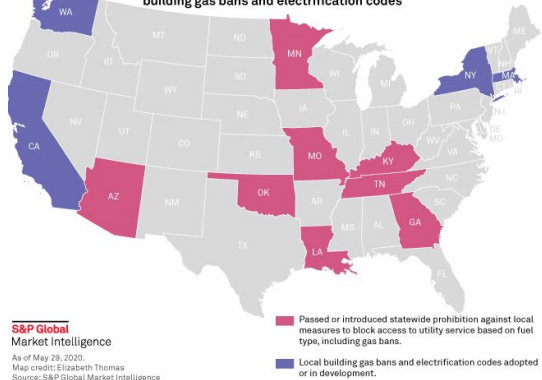


Policy Discussion Expands Nationwide

Building gas bans and all-electric reach codes passed in California
Natural gas utility service areas as defined by California Energy Commission



States advancing or prohibiting building gas bans and electrification codes

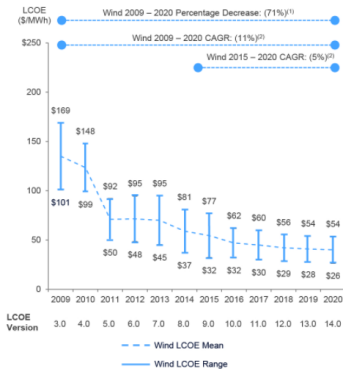


Cheap, Clean Electricity

Levelized Cost of Energy Comparison—Historical Renewable Energy LCOE Declines

In light of material declines in the pricing of system components and improvements in efficiency, among other factors, wind and utility-scale solar PV have exhibited dramatic LCOE declines; however, as these industries have matured, the rates of decline have diminished

Unsubsidized Wind LCOE

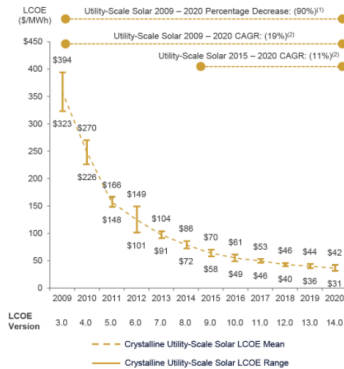


Source: Lazard estimates.

(1) Represents the average percentage decrease of the high end and low end of the LCOE range.

(2) Represents the average compounded annual rate of decline of the high end and low end of the LCOE range.

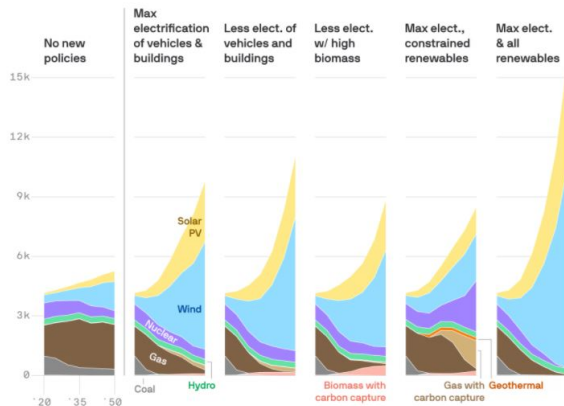
Unsubsidized Solar PV LCOE



Electrification Crucial in Scenario Analyses

U.S. energy mix in five paths to net-zero emissions

Annual generation in terawatt hours, 2020 to 2050



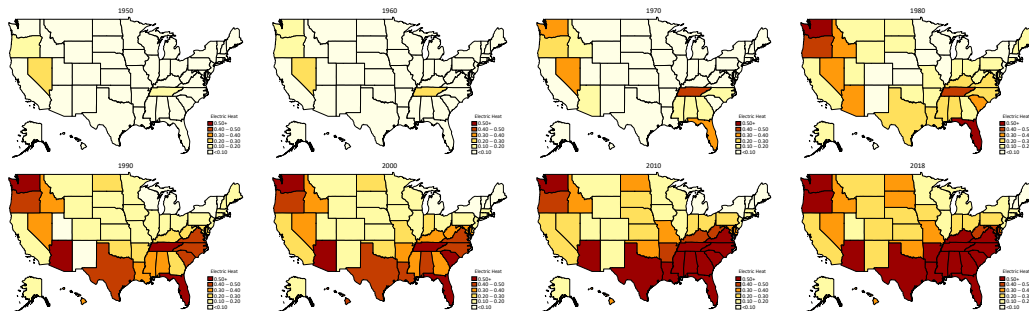
Reproduced from [Net Zero America](#); Chart: Axios Visuals

Proponents versus Critics

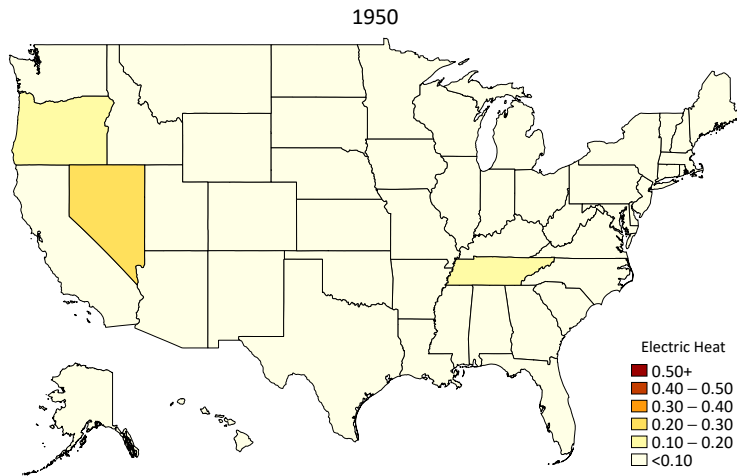
Proponents argue that electrification is critical if the United States is to sharply reduce carbon dioxide emissions from the building sector.

Critics argue that electric heating costs more than natural gas, so electrification mandates are expensive and regressive.

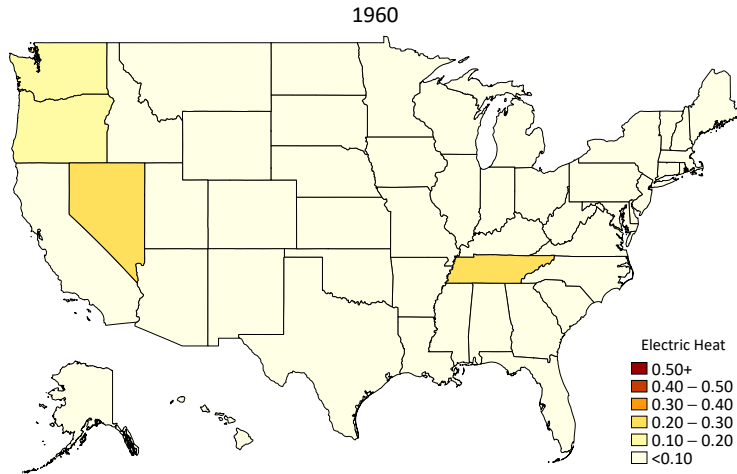
Percentage of U.S. Homes Heated With Electricity



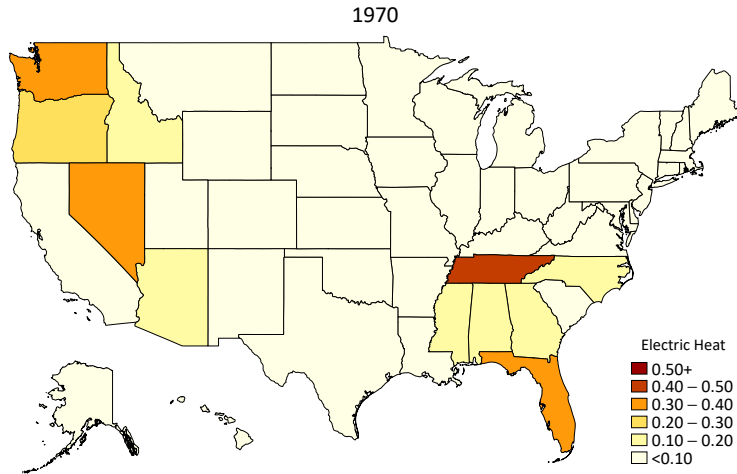
1% of U.S. Homes Heated With Electricity



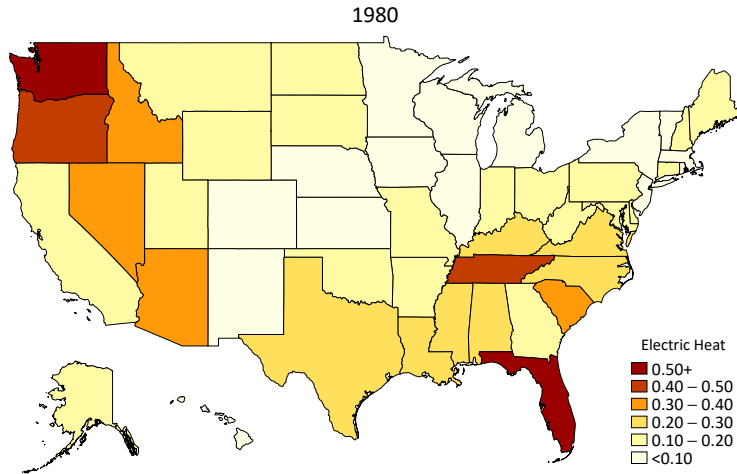
2% of U.S. Homes Heated With Electricity



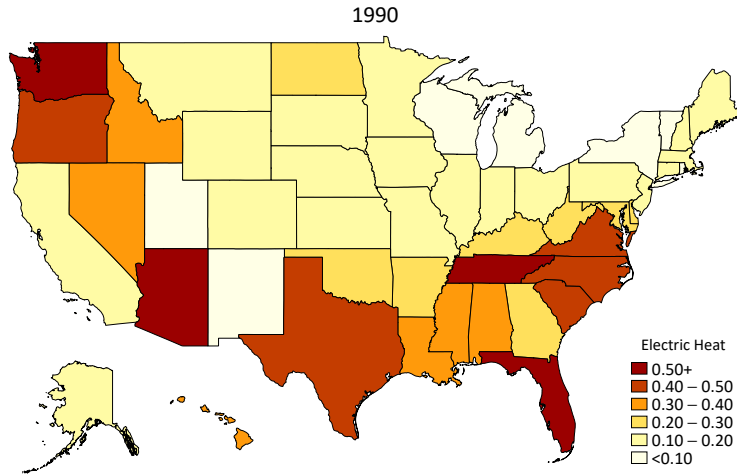
8% of U.S. Homes Heated With Electricity



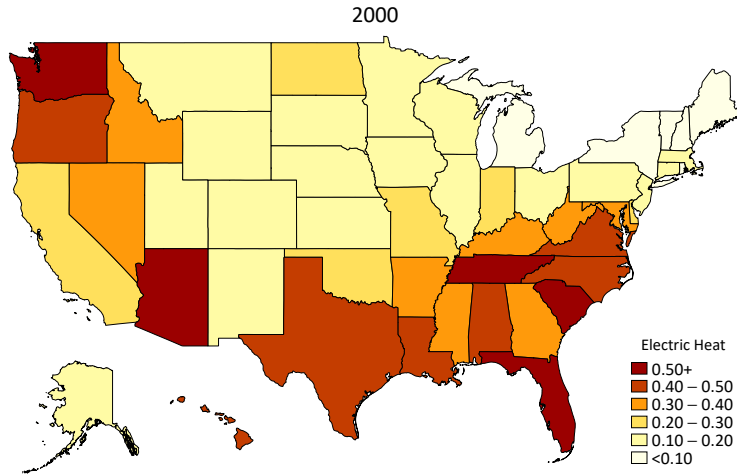
18% of U.S. Homes Heated With Electricity



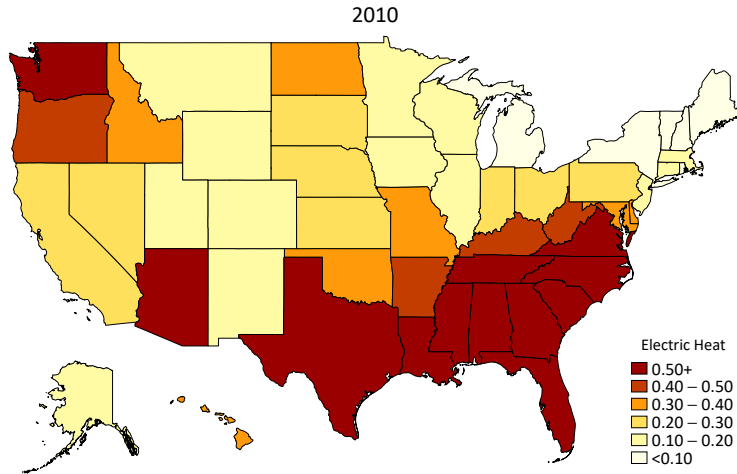
26% of U.S. Homes Heated With Electricity



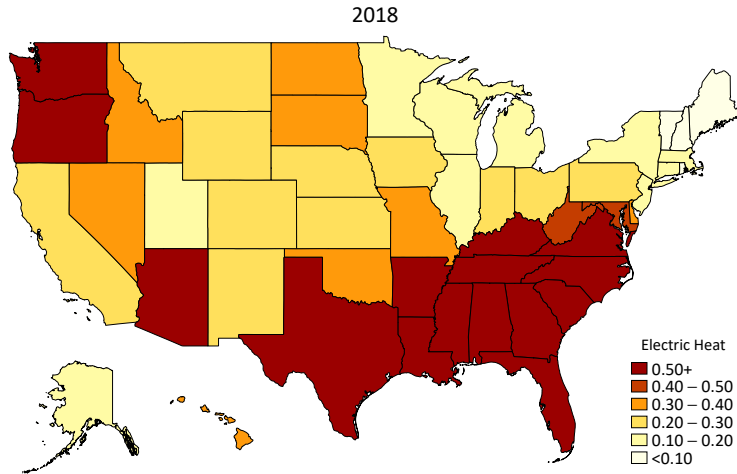
30% of U.S. Homes Heated With Electricity



35% of U.S. Homes Heated With Electricity



39% of U.S. Homes Heated With Electricity



Research Questions

- (1) What Explains the Increase in Electrification of U.S. Home Heating Since 1950?
- (2) How Much Would Households be WTP to Avoid an Electrification Mandate?

Summary of Results

(1) What Explains the Increase in Electrification of U.S. Home Heating Since 1950?

Changing energy prices by far the largest single explanation. Geography, climate, housing characteristics matter too. Income growth has almost zero effect.

(2) How Much Would households be WTP to Avoid an Electrification Mandate?

Households in warm states are close to indifferent between electric and natural gas heating, so would be made worse off by less than \$300 annually.

Household in cold states, however, tend to strongly prefer natural gas so would be made worse off by \$1000+ annually.

Related Literature

- **Economic Analyses of Home Heating** (Dubin and McFadden, 1984; Dubin, 1985; Mansur et al., 2008; Davis and Kilian, 2011)
- **Price Elasticity of Demand for Electricity** (Reiss and White, 2005, 2008; Ito, 2014)
- **Energy-Efficiency Investments** (Allcott and Greenstone, 2012; Gerarden et al., 2017; Gillingham and Palmer, 2014; Fowlie et al., 2018)
- **Cost-Effectiveness of Building Codes** (Aroonruengsawat et al., 2012; Jacobsen and Kotchen, 2013; Levinson, 2016; Kotchen, 2017)
- **Efficient Pricing of Electricity and Natural Gas** (Sherman and Visscher, 1982; Naughton, 1986; Davis and Muehlegger, 2010; Borenstein and Davis, 2012; Borenstein and Bushnell, 2018)

Data

Household-Level Data on Home Heating Choices

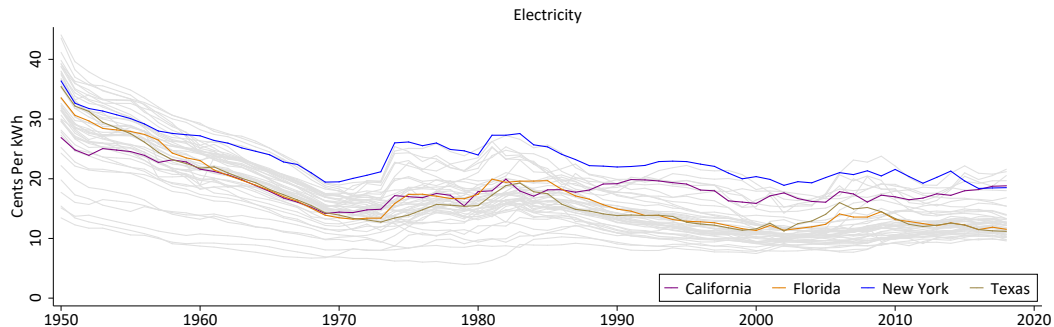
- Five waves of the U.S. Census: 1960, 1970, 1980, 1990, and 2000
- Ten waves of the U.S. American Community Survey: 2000-2018.
- Key question *“Which fuel is used most for heating this house?”*
- Also know household income, age of home, and home characteristics

Residential Energy Prices from DOE/EIA SEDS, plus Edison Electric Institute (1950-1969), American Gas Association (1950-1969), and Platts Oil (1950-1969).

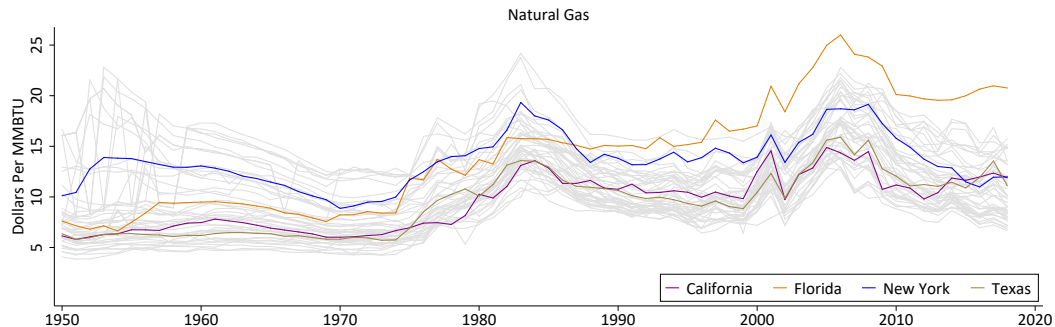
Heating Degree Days by State and Year from NOAA

Merged Dataset is Restructured to Examine Choices at Time of Construction

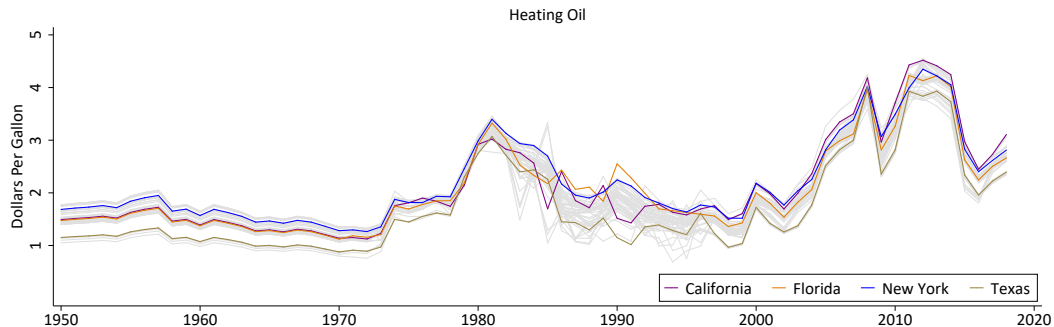
U.S. Residential Electricity Prices By State



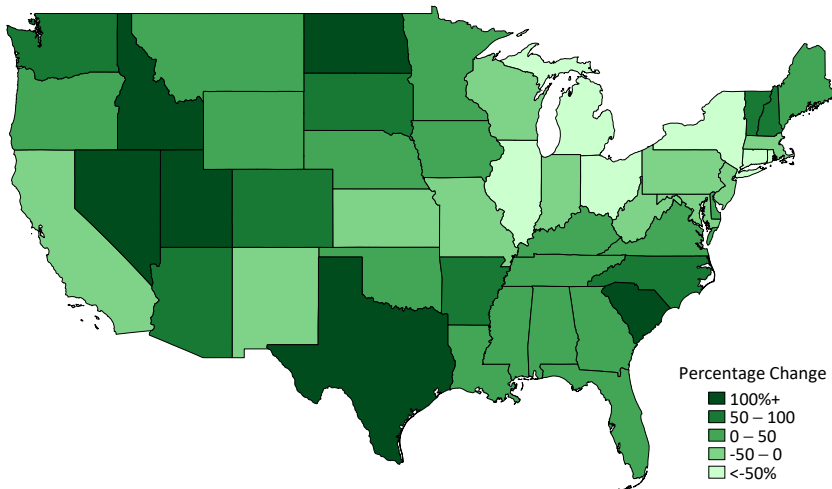
U.S. Residential Natural Gas Prices By State



U.S. Residential Heating Oil Prices By State



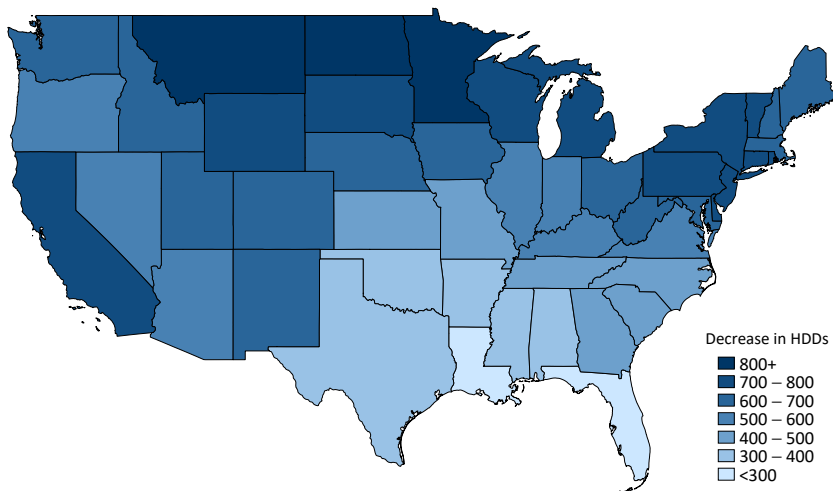
Change in the Distribution of Population Since 1950s



Descriptive Statistics

	1950s	1960s	1970s	1980s	1990s	2000s	2010s
D. Percentage of New Homes By Region							
Northeast	19	17	13	13	10	9	10
Midwest	25	24	22	17	20	19	17
South	34	38	42	47	47	48	52
West	22	21	23	24	23	23	21

Decrease in Heating Degree Days Since 1950



Descriptive Statistics

	1950s	1960s	1970s	1980s	1990s	2000s	2010s
E. Household Demographics and Housing Characteristics							
Household Income (1000s)	61	74	66	80	98	99	106
Home Ownership (percent)	78	67	68	63	74	71	62
Multi-Unit (percent)	19	27	29	30	20	22	31
Number of Bedrooms	2.5	2.6	2.6	2.5	2.9	3.0	2.9

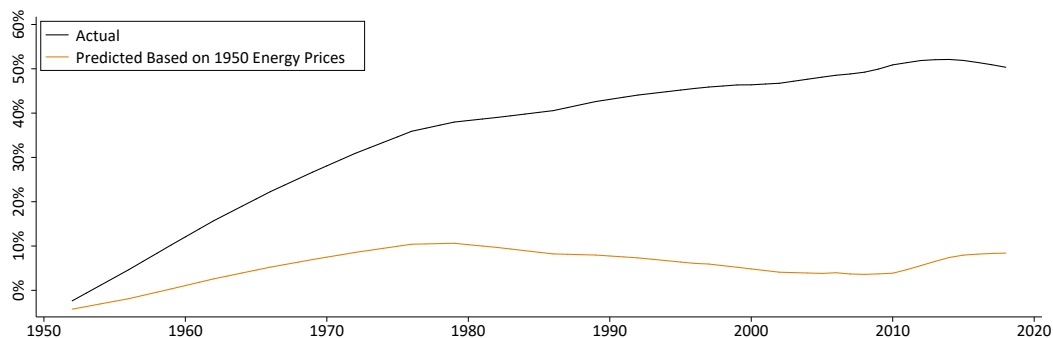
Linear Probability Model, Estimates (1 of 2)

	(1)	(2)	(3)	(4)	(5)	(6)
Electricity Price, in logs	-0.40** (0.03)	-0.43** (0.04)	-0.38** (0.03)	-0.40** (0.05)	-0.40** (0.04)	-0.42** (0.06)
Natural Gas Price, in logs	0.21** (0.06)	0.29** (0.08)	0.18** (0.05)	0.24** (0.07)	0.15** (0.05)	0.21** (0.07)
Heating Oil Price, in logs	0.04 (0.04)	-0.08 (0.15)	0.08* (0.03)	0.08 (0.10)	0.09** (0.03)	0.06 (0.10)
Household Income, 1000s	-0.00** (0.00)	-0.00** (0.00)	-0.00** (0.00)	-0.00** (0.00)	-0.00** (0.00)	-0.00** (0.00)
Heating Degree Days, 1000s	-0.06** (0.01)	-0.06** (0.01)	-0.09** (0.02)	-0.04* (0.02)	-0.05** (0.01)	-0.06** (0.01)
Year Fixed Effects	No	Yes	No	Yes	No	Yes
Geographic Fixed Effects	No	No	Regions	Regions	Divisions	Divisions
Observations	4,163,308	4,163,308	4,163,308	4,163,308	4,163,308	4,163,308
R-squared	0.26	0.28	0.27	0.28	0.27	0.29

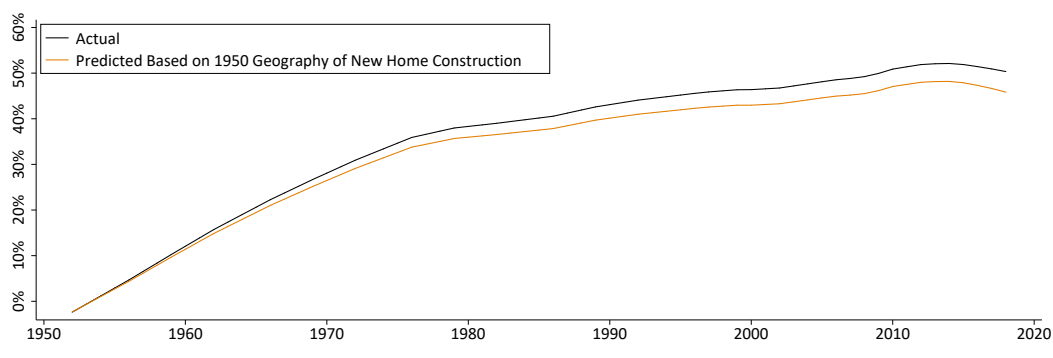
Linear Probability Model, Estimates (2 of 2)

	(1)	(2)	(3)	(4)	(5)	(6)
Four Bedroom Home	-0.05** (0.01)	-0.05** (0.01)	-0.05** (0.01)	-0.04** (0.01)	-0.05** (0.01)	-0.05** (0.01)
Five+ Bedroom Home	-0.10** (0.01)	-0.08** (0.01)	-0.10** (0.02)	-0.08** (0.02)	-0.10** (0.01)	-0.08** (0.02)
Rented, i.e. not owned	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.02* (0.01)	0.02* (0.01)	0.02** (0.01)
Single Family, Attached	0.04* (0.02)	0.04** (0.01)	0.04** (0.01)	0.04** (0.01)	0.04** (0.01)	0.03** (0.01)
Multi-Unit Home, 2-4 Units	0.12** (0.01)	0.12** (0.01)	0.13** (0.01)	0.12** (0.01)	0.12** (0.01)	0.12** (0.01)
Multi-Unit Home, 5+ Units	0.25** (0.02)	0.24** (0.02)	0.25** (0.02)	0.24** (0.02)	0.25** (0.02)	0.24** (0.02)
Year Fixed Effects	No	Yes	No	Yes	No	Yes
Geographic Fixed Effects	No	No	Regions	Regions	Divisions	Divisions
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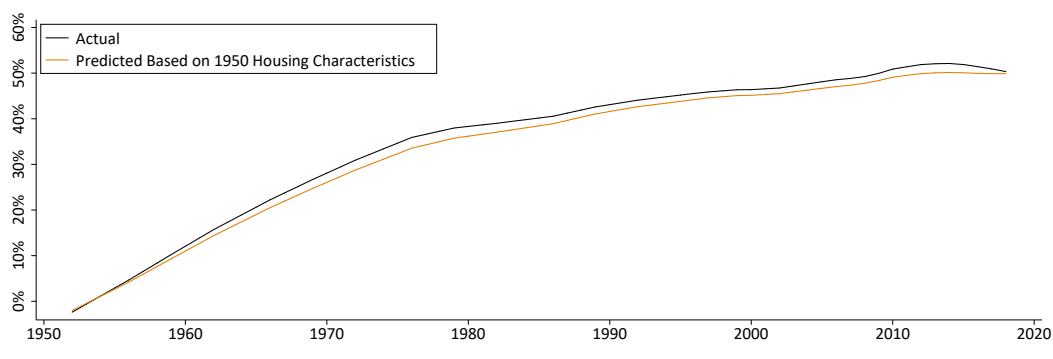
Counterfactual Analysis: 1950s Energy Prices



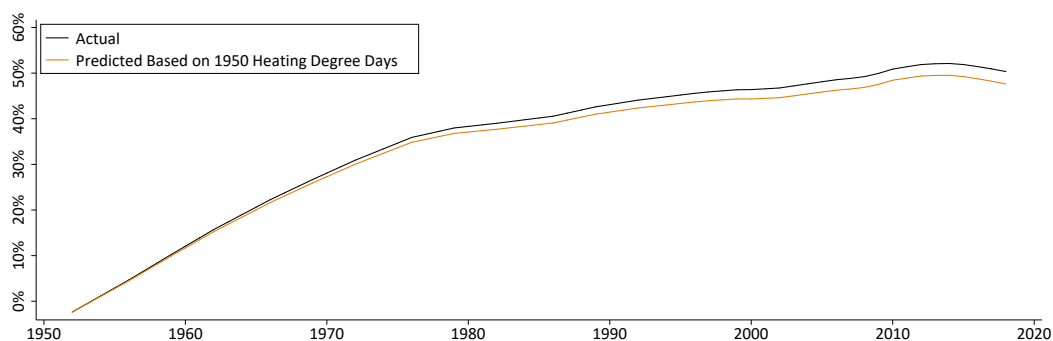
Counterfactual Analysis: 1950s Distribution of Population



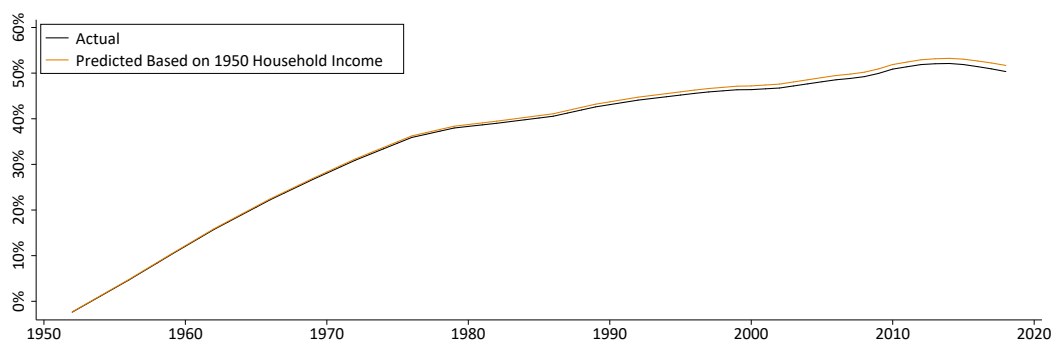
Counterfactual Analysis: 1950s Housing Characteristics



Counterfactual Analysis: 1950s Heating Degree Days



Counterfactual Analysis: 1950s Household Income

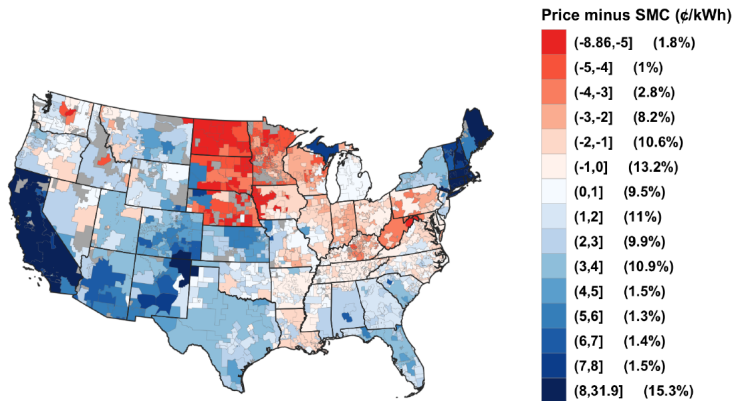


Decomposition Results

What Explains the Increase in Electrification of U.S. Home Heating Since 1950?

- Changing Energy Prices? **82%**
- Changing Distribution of Population? **7%**
- Changing Housing Characteristics? **4%**
- Climate Change (i.e. HDDs)? **4%**
- Rising Household Income? **-1%**

Is Electricity Priced Efficiently in the U.S.?



Source: Borenstein and Bushnell, "Do Two Electricity Pricing Wrongs Make a Right? Cost Recover, Externalities, and Efficiency", 2021.

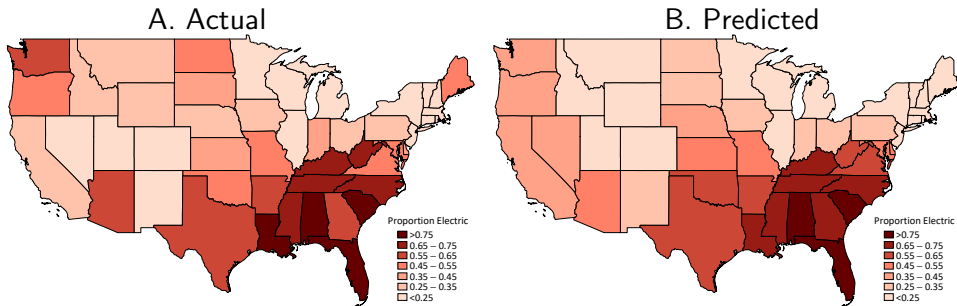
Estimating Willingness-to-Pay

How Much Would U.S. Households be WTP to Avoid an Electrification Mandate?

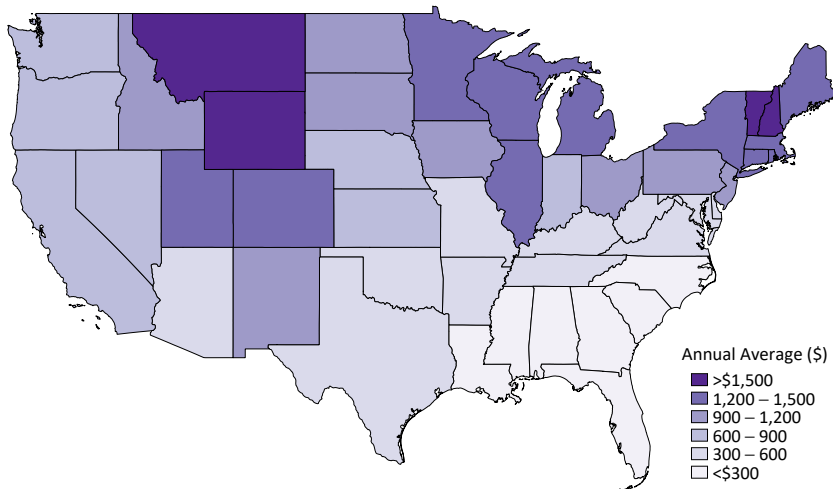
A standard discrete choice model is used for this analysis.

I estimate the model using heating system choices for homes built since 1990.

Evaluating the Fit of the Discrete Choice Model



Willingness-to-Pay to Avoid Electrification Mandate



Glass Half Full, or Half Empty?

One implication of the research is that, nationally, it may be a lot easier than is generally believed to encourage electrification.

The historical trend over the last seven decades means that millions of U.S. households have already “electrified”. Moreover, the analysis identifies millions of additional households, mostly in warmer states, for whom adopting electric heating would impose relatively modest costs.

On the other hand, the analysis also underscores the significant lift it would take to electrify colder states, where the vast majority of emissions come from.

Thank You!

