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The Cost of Adapting to Climate Change: Evidence from the US Residential Sector

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Motivation

- Over the next decades, climate will change with certainty
  - At best, limited to a 2°C increase relative to pre-industrial levels
- But the cost is uncertain because the adaptation potential is difficult to predict
- In particular, this applies to climate econometrics
  - Panel data approaches which exploit weather shocks within a given spatial area to identify impact of climate change on various economic outcomes
- Why?
  - Because assess the short term impact of weather shocks leaving no time to economic agents to adapt

The new climate - economy literature (Dell et al 2014, JEL)

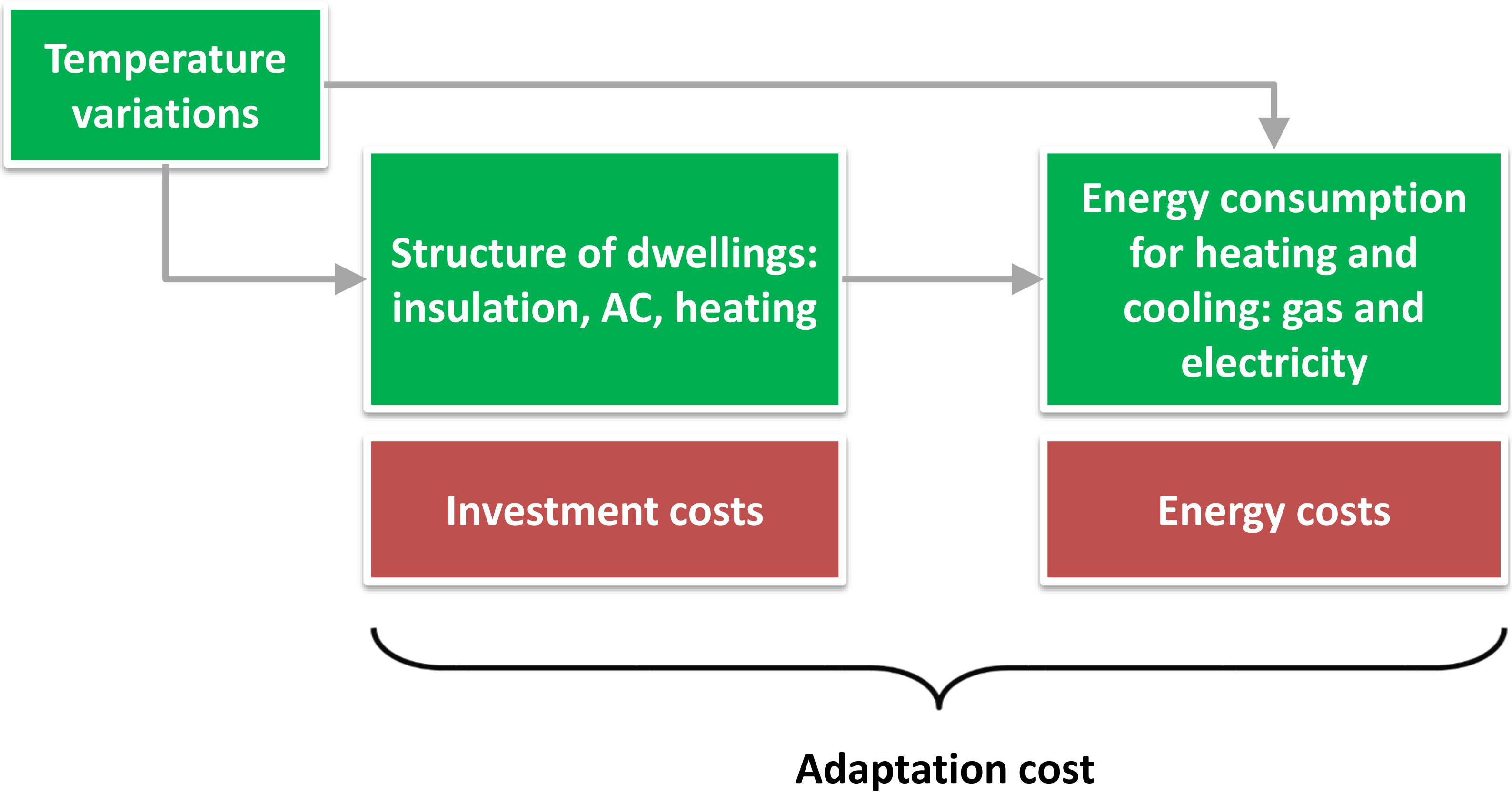
- **Panel methods which exploit weather shocks within a given spatial area to identify impact of climate change on various economic outcomes**
  – Per capita income, growth, agriculture, labor, industrial outputs, health and mortality, political stability, energy consumption, crime
- **These works hardly look at adaptation**
  – Reduced-form approach
  – Assess the short term impact of climate shocks
- **Our contribution**
  – To focus on dwellings, a central technology to adapt to climate conditions
  – To enter the black box of adaptation

Adaptation in the residential sector

- Adaptation involve multiple decision makers and different time horizons.
- From the short term to the long term:

1. Adjusting energy use (less heating, more cooling)
2. Modifying the structure of the dwelling (investing in AC, insulation…)
3. Building new dwellings
4. Innovating in cooling technologies
5. Redesigning urban space

This paper: the adaptation of existing dwellings



What we do

- Data: A panel of housing units located in 160 MSAs between 1985 and 2011 (around 58,000 observations)
  - Detailed information on investments made in home improvements, energy use
- A panel data analysis to identify the impact of location-specific temperature variations on:
  1. The volume of adaptation-related investments (purchase of major equipment and weatherization)
  2. Energy expenditure
- Combine the econometric estimates with the output of a climate model in order to predict the adaptation costs and energy use under the IPCC "business-as-usal" A2 scenario
  - A 6.1°F increase in 2090-2099 relative to 1980-1999

Data sources

- **American Housing Survey:**
  - Micro data that describe home improvements in 10,522 housing units from 1985 to 2011, in particular, the purchase of major equipment and weatherization, energy use, home occupiers, the location (the MSA)
  - 14 waves = biannual
- **Global Historical Climatology Network Daily:**
  - Construct temperature variables from 22,000 stations
  - Match all currently and formerly operating stations within a 50km radius of the centroid of each MSA
- **ECHAM model:**
  - An atmospheric general circulation model developed at the Max Planck Institute for Meteorology
  - Provide state-level monthly average temperature predictions for 2080 – 2099 under the A2 scenario

Preview of the findings

- The present discounted value of the cost for adapting homes to the "business-as-usual" scenario is **$5,600** per housing unit, but not statistically different from zero.
  - Around 2.7% of the average purchase price of the housing units
- Important disparities between hot regions and cold regions.
- A major shift from gas (-25%) to electricity (+29%)

Summary statistics

Table 1: Descriptive statistics of AHS data

Variable	Unit	Mean	Std. deviation
Investments in equipment			
Capitalized investments	$	9,861	6,672
Respondents declaring an investment	%	7.6	-
Expenditure if an investment is made	$	3,654	2,600
Investments in weatherization			
Capitalized investments	$	52,431	40,732
Respondents declaring an investment	%	20.0	-
Expenditure if an investment is made	$	3,646	4,018
Investments in other indoor amenities			
Capitalized investments	$	99,848	77,114
Respondents declaring an investment	%	34.2	
Expenditure if an investment is made	$	4,835	6,752
Energy expenditure and consumption			
Annual electricity expenditure	$	1,335	740
Annual gas expenditure	$	733	654
Annual electricity consumption	MM.btu/year	35.3	20.5
Annual gas consumption	MM.btu/year	64.1	57.5
Other relevant variables			
Number of people in household	#	2.83	1.52
Housing units connected to pipe gas	%	80.8	-
Commuting time	min.	21	17
Square footage of unit	sq. ft.	2,179	1,260
House price at time of purchase	$	205,218	156,757

Notes. Source: AHS. Survey years: 1985-2011. Max. number of observations: 49,576. Comments: all the variables in dollars are expressed in 2011 real dollars. The correction of nominal values was made using the US Consumer Price Index of the Bureau of Statistics of the US Department of Labor.

Model 1: Investment

- Two investment equations:
  1. purchase of large equipment (e.g. air conditioners, heaters)
  2. insulation (e.g. roofing, siding, window replacements)
- Panel data model with time and household fixed effects:

$$I_{iht} = \alpha_h CDD_{it} + \beta_h HDD_{it} + \gamma_h X_{it} + \mu_{ih} + \tau_{ht} + \varepsilon_{iht}$$

with

- I_{iht} = the volume of investment made in year *t* by household *i* in investment *h*
- CDD_{it} = expected cooling degree days
- HDD_{it} = expected heating degree days
- X_{it} = household size, access to energy, precipitations
- μ_{ih} = by-home-by-category fixed effects
- τ_{ht} = time dummies
- ε_{iht} = a random noise

Temperature variables

- Annual heating degree days = sum of degrees below 65°F based on average daily temperatures
  - Used by engineers to compute annual heating needs;
- Annual cooling degree days = sum of degrees above 65°F
- Not the contemporaneous value, but a weighted average of past values
  - Households are aware of inter-annual temperatures variations
  - Consistent with the adaptive expectation model
- Robustness checks with temperature bins
- # days with precipitation as a control

Other controls

- **The choice of adequate controls is complicated** by the fact that the climate potentially influences many candidate variables.
  - Income affects investment levels, but is also affected by the climate (e.g., Dell et al. 2009).
  - Risk of "over-controlling": Dell et al. (2014) and Hsiang (2016).
- **We do not incorporate:**
  - Income
  - Local price of investments
  - Local energy prices
  - Past investments, who depend on past expectations about the climate.
- **We incorporate:**
  - Time and household fixed effects
  - Number of individuals living in the house
  - Whether the house is connected to pipe gas
- **Energy efficiency policies? 2% of observations withdrawn.**
  - Robustness check when grants or loans are treated as an endogenous variable

Main results: Investments

Type of investment	Equipment	Weatherization
Expected heating degree days	0.106**	0.328**
	(2.12)	(2.14)
Expected cooling degree days	0.264**	0.441**
	(2.31)	(1.97)
Expected precipitations	-0.00159	0.0291
	(-0.22)	(1.41)
No. people in unit	6.039	23.31
	(0.62)	(1.20)
Connection to pipe gas	225.0***	245.5***
	(3.68)	(2.78)
Observations	42,221	42,010

Notes: t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Models include household fixed effects and time-dummies. Constant terms are not reported. Standard errors are clustered at household level.

Using temperature bins

Type of investment	Equipment	Weatherization
Expected # days with temperature:		
Below 10°F	1.349	8.333
	(0.23)	(0.64)
Between 10-20°F	10.78**	21.75**
	(2.10)	(2.02)
Between 20-30°F	-5.469	7.710
	(-1.47)	(0.96)
Between 30-40°F	3.687*	10.90*
	(1.92)	(1.77)
Between 40-50°F	2.437	7.812
	(1.04)	(1.47)
Between 50-60°F	2.810	7.938*
	(1.38)	(1.83)
Between 60-70°F	-	-
Between 70-80°F	2.343	4.618
	(1.31)	(1.21)
Between 80-90°F	4.414*	9.424*
	(1.74)	(1.93)
Above 90°F	14.03**	23.62**
	(2.11)	(2.41)
Expected days with precipitations:		
No precipitation	-	-

Robustness checks: investments

- 1: Contemporaneous and lagged values of climate variables
- 2: Left-censored investment models
- 3: Excluding improvements made just before households leave the unit
- 4: Using observations that benefitted from a public grant or a loan
- 5: Interaction between time and climate variables
- 6: Investment model of other indoor amenities

Model 2: Energy expenditure

- A fixed effect panel data model with year and household fixed effects. dependent variable is :

$$\ln\left(E_{ift}\right) = \theta_f cdd_{it} + \lambda_f hdd_{it} + \sum_{h=1}^{3} \phi_{hf} K_{iht} + \omega_f Y_{it} + \mu_{if} + \tau_{ft} + \epsilon_{ift}$$

with

- $\ln\left(E_{ift}\right)$: the logarithm of the annual consumption in home *I* in year t
- of fuel f (gas or electricity)
- cdd_{it} and hdd_{it} = cooling and heating degree days in year t in home I (current values)
- K_{iht} = the stock of past investments defined by $K_t = I_t + \rho K_{t-1}$ where ρ is a depreciation factor measuring the decay of past investments.
- Y_{it} = household size, access to energy
- μ_{if} = by-household-by-fuel fixed effects
- τ_{ft} = time dummies
- ϵ_{ift} = a random noise

Endogeneity issues

- Capital stocks variables are likely to be endogenous
  - they include the investments I_{iht} made in year t, which are simultaneously determined with E_{ift}
- Solution = System-GMM estimator with capital stocks instrumented with their lagged values

Main results: energy expenditures

Dependent variable	Ln. Electricity Expenditure		Ln. Gas Expenditure	
	(1)	(2)	(3)	(4)
Heating degree days	0.0137***	0.00808	0.142***	0.139***
	(2.96)	(1.43)	(24.89)	(23.65)
Cooling degree days	0.176***	0.129***	0.0868***	0.0856***
	(16.07)	(6.15)	(6.02)	(5.93)
Capital in equipment	0.0131***		0.00385	
	(2.59)		(0.62)	
x heating fuel is electricity		0.0176		
		(1.48)		
x AC fuel is electricity		0.0203***		
		(2.61)		
x heating fuel is gas				0.0184**
				(1.99)
x AC fuel is gas				0.00104
				(0.05)
Capital in weatherization	-0.00360**	-0.00287*	-0.00219	-0.00291
	(-2.09)	(-1.68)	(-1.04)	(-1.38)
Capital in other amenities	0.00141	0.00128	0.00218**	0.00122
	(1.59)	(1.44)	(2.04)	(1.12)
Precipitations	0.0139***	0.0146***	0.0154***	0.0161***
	(17.98)	(18.57)	(15.45)	(15.35)
No. people in unit	0.0852***	0.0852***	0.0433***	0.0444***
	(38.78)	(39.09)	(17.92)	(18.20)
Connection to pipe gas	-0.173***	-0.0925*	0.193***	0.160***
	(-20.24)	(-1.66)	(5.14)	(3.95)
Observations	50,000	50,000	37,244	37,244
Hansen test	0.12	0.36	0.09	0.16
Number of instruments	85	107	85	107

Robustness checks: energy expenditure

- 1: Expenditure models with bins
- 2: Energy expenditure models using orthogonal deviations instead of first differences
- 3: Energy expenditure models with 4th lags as instrument
- 4: Energy expenditure model using difference GMM
- 5: Energy expenditure models without capital variables
- 6: Region-specific elasticities to temperature shocks
- 7: Dynamic energy expenditure model
- 8: Using energy consumption instead of energy expenditure

Simulations of the A2 scenario for the end of the century (2080-2099)

A2 is a business-as-usual scenario leading to a global average surface warming of 6.1°F in 2090-2099 relative to 1980-1999

More specifically, an increase in # very hot days:

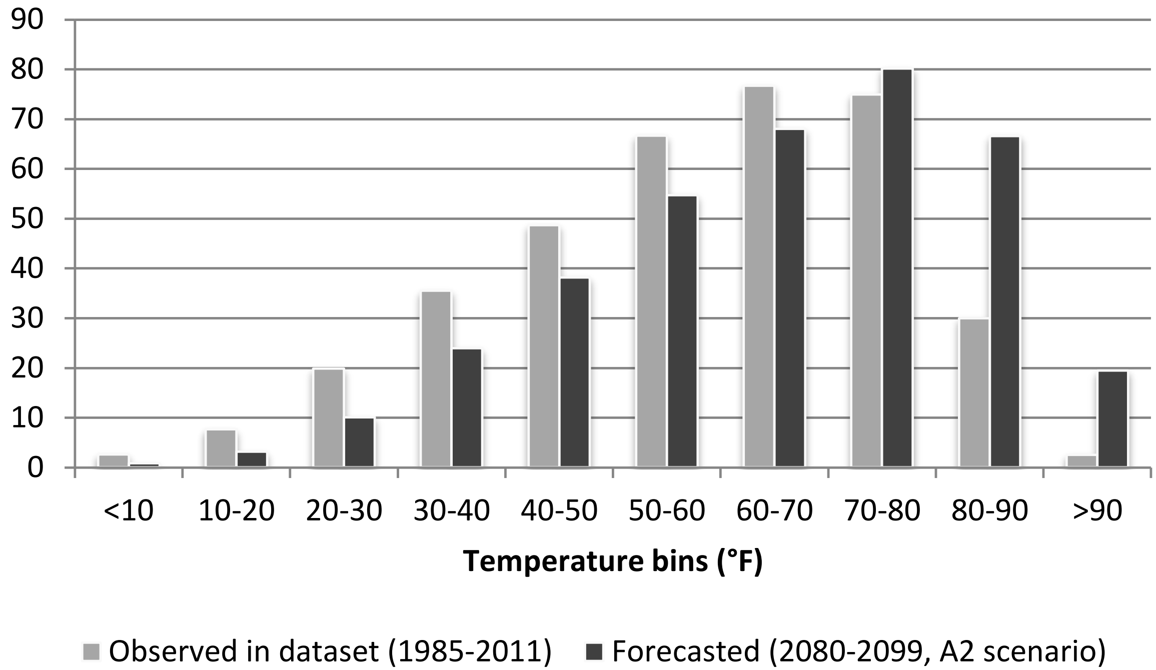


Figure 2: Observed and forecasted number of days falling within each temperature bin

Results, nationwide

Estimated impact of the A2 scenario (2080-2099) on annual investments and energy expenditure for a representative US housing unit

	Sample average 1985-2011	Variation under the A2 scenario		
		In level		In percent
		Mean	95% confidence interval	
Annual investment in equipment	$131	+$73	[-$59, +$205]	+56%
• *For heating*		-$81**	[-$156, -$6]	-
• *For cooling*		+$154**	[+$23, +$285]	-
Annual investment in weatherization	$362	+$7	[- $380, + $320]	+2%
Annual electricity bill	$1,304	+$374***	[+$134, +$717]	+29%
Annual gas bill	$684	-$168***	[-$282, -$73]	-25%
Total annual energy expenditure	$1,988	+$252*	[-$33, +$626]	+13%
Present discounted cost of adaptation†	-	+$5,578*	[-$358, +$12,976]	-

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. † Discounted cost of adaptation is calculated for 25 years with a 4% discount rate. All monetary numbers are in 2011$.

Results, by region

Estimated impact of the A2 scenario (2080-2099) on for a representative US housing unit in different US regions

US Climate Region (as defined by NOAA)	Present discounted cost of adaptation
Central	+$3,062
Northwest and	-$3,417
West North Central	+$5,762
East North Central	-$842
Northeast	+$4,402
South	+$28,570***
Southeast	+$8,493***
Southwest	+$18,216***
West	+$7,394***

Without capital adjustments

Type of expenditure	Sample average 1985-2011	Variation under the A2 scenario		
		In level		In percent
		Mean	95% confidence interval	
Annual electricity bill	$1,304	+$206***	[+$143; +$272]	+16%
Annual gas bill	$684	-$82***	[-$69; -$95]	-12%
Total annual energy expenditure	$1,988	+$124***	[+$48; +$203]	+6%
Present discounted cost of adaptation†	-	+ $2,058***	[+ $802; + $3,378]	-

Under-estimation of the impacts

Conclusion

- A novel approach where we look inside the « black box » of adaptation
- In average, the US residential sector seems resilient to predicted temperature increases
  - But huge disparities across States
- Climate change would have a very strong impact on the composition of residential energy consumption
  - Less gas (in colder States)
  - Much more electricity (in hotter States)
- Failure to account for capital adjustments leads to underestimate the impacts

Thanks!