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# Adapting the US Residential Sector to Global Warming

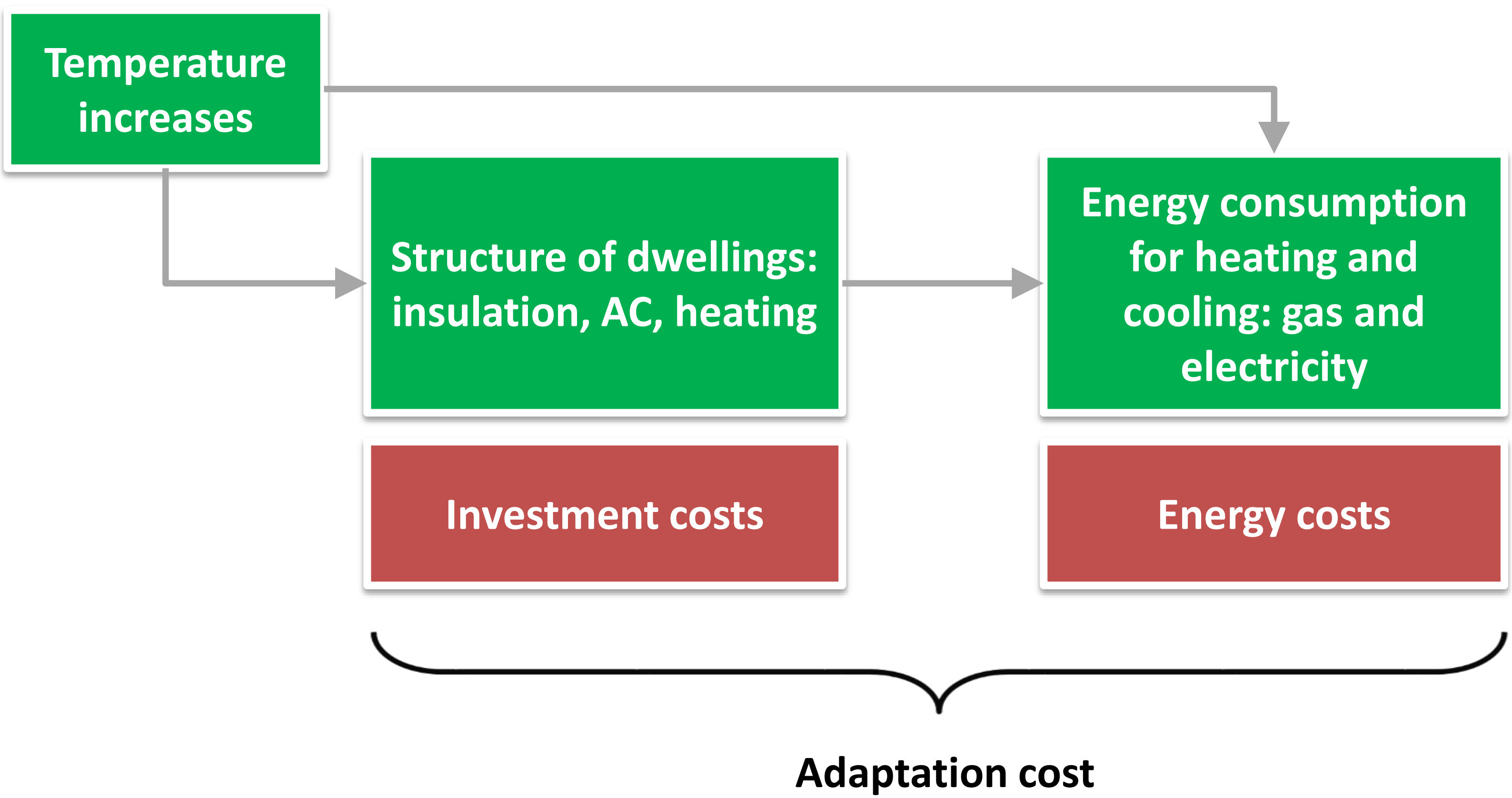
**Francois Cohen[a], Matthieu Glachant[b] and Magnus Söderberg[c]**

a: London School of Economics and Political Science, UK.
b: MINES ParisTech, France.
c: University of Gothenburg, Sweden

# 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, in particular, because the adaptation potential is difficult to predict
- Different adaptation strategies have different costs and impacts
  - Dikes to protect from sea level rise
  - Changes in crop-management practices in agriculture
  - Installation of insulation of housing to protect from heat
  - Their evaluation is crucial to devise efficient policy solutions
- In this paper, adaptation of the US residential sector
  - Existing dwellings

# The impact of climate change on existing dwellings



# Questions

- What is the economic cost of adapting existing homes to temperature increases?
  - Home renovation costs + energy expenditures
- What is the impact of temperature increases on residential energy use?
  - Accounting for adaptation/investment

# What we do

- Use dwelling-level data on home improvements and energy consumption (American Housing Survey, 1985-2011)
  - 58,529 observations from 126 Metropolitan Statistical Areas
- A two-stage panel data analysis to identify the impact of location-specific temperature variations on 1) investment; 2) energy expenditures
- Simulations of the IPCC “business-as-usal” A2 scenario
  - Combine our econometric estimates with the output of the ECHAM general circulation model (a 3.4°C increase in 2090-2099 relative to 1980-1999) to predict adaptation costx and energy expenditures by the end of the century

# Preview of the findings

- The present discounted value of the cost for adapting homes to the "business-as-usual" scenario is **$7,200** per housing unit, but this value is not statistically different from zero.
  - Around 3.4% of the average purchase price of the housing units
  - 0.5% of the sample average annual household income if translated into annual expenditures.
- This number hides important disparities between hot regions where households would invest massively in air conditioning and cold regions which would benefit from milder winters.
- Relatedly, a major shift from gas to electricity
  - Residential electricity consumption would increase by 34% (mostly, in hotter States)
  - Residential gas consumption would fall by 17% nationwide (mostly in colder States).
  - In total, energy expenditures would increase by 14%.

# How are economic damages of climate change estimated in the literature?

Two approaches (Tol, 2009)

- The enumerative method
  - Estimates of the "physical effects" of climate change obtained one by one from natural science papers
  - The physical impacts are then each be given a price
  - Ex: Agricultural models give the impact of temperature on wheat yield. Yields losses are valued at the wheat market price
- The statistical (or econometric) method
  - Direct estimates of the economic impacts, using observed variations in prices and expenditures to discern the effect of climate
  - Ex: To correlate farmers' income with temperature variations

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

- Panel data 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
  - Assess the short term impact of weather shocks leaving no time to economic agents to adapt
- Only two papers on the residential sector
  - Deschênes and Greenstone (2011) and Auffhammer and Aroonruengsawat (2011, 2012) on residential energy consumption
  - Holding fixed the stock of energy-related durables

# Data sources

- **American Housing Survey:**
  - Covering about 160 Metropolitan Statistical Areas (MSA) all over the US
  - 14 survey waves with same panel: 1985-2011
  - Describe home improvements, in particular, the purchase of major equipment and weatherization, and energy use
- **Global Historical Climatology Network Daily:**
  - Match all currently and formerly operating stations within a 50km radius of the centroid of each MSA
  - Construct climate averages from 22,000 stations
- **ECHAM model:**
  - An atmospheric general circulation model developed at the Max Planck Institute for Meteorology
  - State-level monthly average temperature predictions drawn from the 5th version

# Summary statistics

| Variable | Unit | Mean | Std. deviation |
|---|---|---|---|
| *Investments in equipment* | | | |
| Capitalized investments | $ | 10,201 | 7,641 |
| Respondents declaring an investment | % | 7.4 | - |
| Expenditure if an investment is made | $ | 3,978 | 2,891 |
| *Investments in weatherization* | | | |
| Capitalized investments | $ | 54,534 | 40,732 |
| Respondents declaring an investment | % | 16.6 | - |
| Expenditure if an investment is made | $ | 4,817 | 4,904 |
| *Investments in other indoor amenities* | | | |
| Capitalized investments | $ | 104,368 | 77,114 |
| Respondents declaring an investment | % | 29.1 | |
| Expenditure if an investment is made | $ | 6,730 | 10,101 |
| *Energy expenditure and consumption* | | | |
| Annual electricity expenditure | $ | 1,379 | 819 |
| Annual gas expenditure | $ | 742 | 723 |
| Annual electricity consumption | MM.btu/year | 36.7 | 23.0 |
| Annual gas consumption | MM.btu/year | 64.8 | 63.0 |
| *Other relevant variables* | | | |
| Number of people in household | # | 2.82 | 1.52 |
| Housing units connected to pipe gas | % | 79.1 | - |
| Commuting time | min. | 22 | 16 |
| Square footage of unit | sq. ft. | 2,189 | 1,267 |
| House price at time of purchase | $ | 211,310 | 174,966 |

# 1) Investment

- Two investment categories:
  1. purchase of large equipment (e.g. air conditioners, heaters)
  2. insulation (e.g. roofing, siding, window replacements)
- The dependent variable is $I_{iht}$, the volume of investment made in year *t* in home *i* in category *h:*

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

With

- $C_{it}$ = a vector of climate variables
- $X_{it}$ = household size, access to energy
- $\mu_{ih}$ = by-home-by-category fixed effects
- $\tau_{ht}$ = time dummies
- $\varepsilon_{iht}$ = a random noise

# The climate variables

- Annual heating degree days = sum of degrees below 65°F based on average daily temperatures (65°F = 18.3°C)
  - Used by engineers to compute heating needs;
- Annual cooling degree days = sum of degrees above 65°F
- # days with precipitation
- Not the contemporaneous value, but a weighted average of past values
  - Households are aware that the climate varies over time
- Robustness checks with temperature bins and contemporaneous values

# Main results: Investment

| Type of investment | Equipment | Weatherization |
|---|---|---|
| Expected heating degree days | 0.161** | 0.322** |
| | (2.23) | (2.08) |
| Expected cooling degree days | 0.354*** | 0.297 |
| | (2.69) | (1.13) |
| Expected precipitations | -0.00399 | 0.0141 |
| | (-0.39) | (0.58) |
| No. people in unit | -4.347 | 41.11* |
| | (-0.42) | (1.70) |
| Connection to pipe gas | 89.83 | 138.1 |
| | (1.55) | (1.43) |
| Observations | 44,975 | 42,900 |

# Energy expenditures

- The dependent variable is $\ln(E_{ift})$: the logarithm of the annual consumption in home *I* of fuel *f* in year t
- Two equations for gas and electricity:

$$\ln(E_{ift}) = \gamma_f \ln(E_{ift-1}) + \theta_f w_{it} + \sum_{h=1}^{3} \phi_{hf} K_{iht} + \omega_f Y_{it} + \mu_{if} + \tau_{ft} + \epsilon_{ift}$$

with

- $w_{it}$ = a vector of **weather** variables
- $K_{iht}$ = the stock of past investments defined by $K_t = I_t + \rho K_{t-1}$ where $\rho$ is a depreciation factor measuring the decay of past investments.
- $Y_{it}$ = household size, access to energy
- $\mu_{if}$ = by-home-by-fuel fixed effects
- $\tau_{ft}$ = time dummies
- $\epsilon_{ift}$ = a random noise

# Econometric issues

- Dynamic panel data model (Blundell-Bond estimator)
  - Energy use driven by persisting consumption patterns
- Lagged energy use instrumented with the time spent in the house
- Investment stocks instrumented with lagged values

# Main results: energy expenditures

| Type of fuel | Electricity | | Gas | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Lagged dependent | 0.402*** | 0.411*** | 0.449*** | 0.410*** |
| variable (log) | (3.86) | (4.08) | (3.25) | (3.05) |
| Heating degree days | 0.00988*** | 0.00605** | 0.0737*** | 0.0781*** |
| | (2.94) | (2.06) | (3.94) | (4.35) |
| Cooling degree days | 0.108*** | 0.0849*** | 0.0192** | 0.0258** |
| | (5.16) | (5.29) | (2.03) | (2.32) |
| Capital in equipment | 0.00411* | -0.00268 | 0.00941*** | -0.00285 |
| | (1.82) | (-1.03) | (3.31) | (-0.44) |
| x heating fuel is electricity | | 0.00513*** | | |
| | | (2.77) | | |
| x AC fuel is electricity | | 0.00732*** | | |
| | | (4.02) | | |
| x heating fuel is gas | | | | 0.0143** |
| | | | | (2.02) |
| x AC fuel is gas | | | | 0.00173 |
| | | | | (0.36) |
| Capital in weatherization | [illegible] | [illegible] | [illegible] | [illegible] |

# 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

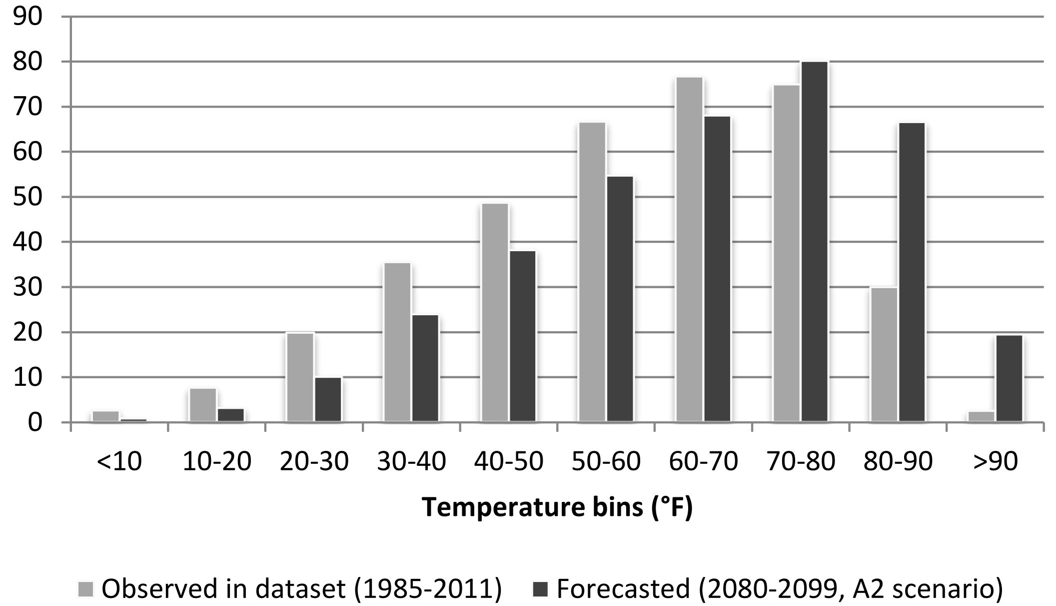



*Figure 2: Observed and forecasted number of days falling within each temperature bin*

# 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 | Baseline long term prediction† | Variation under the A2 scenario | | |
|---|---|---|---|---|---|
| | | | In level | | In percent |
| | | | Mean | 95% confidence interval | |
| Annual investment in equipment | $147 | | + $121 | [- $50, + $293] | +82% |
| • For heating | | | - $113** | [- $213, - $14] | - |
| • For cooling | | | + $235*** | [+ $92, + $377] | - |
| Annual investment in weatherization | $417 | | - $30 | [- $380, + $320] | -7% |
| Annual electricity bill | $1,378 | $1,617 | + $558*** | [+ $272; + $953] | +34% |
| Annual gas bill | $742 | $892 | - $209*** | [- $366; - $73] | -23% |
| Total annual energy expenditures | $2,120 | $2,509 | + $349* | [-$38; +$822] | +14% |
| Present discounted adaptation cost † | | - | + $7,213 | [- $1,332; + $16,918] | - |

# 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) | Investments | | | Energy bills | | | Present discounted cost of adaptation |
|---|---|---|---|---|---|---|---|
| | Heating | Cooling | Weatherization | Electricity | Gas | Total energy | |
| Central | -144** | +173*** | -144 | +300*** | -351*** | -51 | -2,794 |
| East North Central | -158** | +149*** | -192 | +234*** | -354*** | -120 | -5,350 |
| Northeast | -156** | +174*** | -166 | +313*** | -296*** | +17 | -2,213 |
| Northwest | -146** | +86*** | -222* | +73 | -229*** | -156 | -7,322*** |
| West North Central† | -135** | +182*** | -118 | +343*** | -353*** | -9 | -1,301 |
| South | -68** | +355*** | +161 | +1,149*** | -89 | +1,060*** | +25,029*** |
| West | -81** | +267*** | +61 | +540*** | -104** | +436*** | +11,406*** |
| Southeast | -49** | +325*** | +175 | +1031*** | -63** | +969*** | +23,536*** |
| Southwest | -107** | +296*** | +35 | +891*** | -130*** | +767*** | +16,633*** |

# Conclusion

- In average, the US residential sector seems resilient to predicted temperature shocks
  – But huge disparities between States
- But climate change will have a very strong impact on residential energy consumption
  – Less gas (in colder States)
  – Much more electricity (in hotter States)

# Limitations

- The scope of adaptation covered in the study is limited
  - No construction of new buildings
  - No innovation in adaptation technologies
  - No institutional adjustments (urban planning)
- A partial view of climate change impacts on the residential sector
  - Do not evaluate the impact of floods or hurricanes
- Do not account for uncertainties pertaining to the climate model

# Thanks!