The effect of climate change on the level and timing of future electricity demand

Blake Shaffer (Stanford and University of Calgary)
Nicholas Rivers (University of Ottawa)

PIMS Workshop on Mathematical Sciences and Clean Energy
University of British Columbia
May 21, 2019

Introduction

Understanding the effect of climate change is a critical economic, social and policy-relevant question

Recent literature asks:

”How will climate change affect variable X?”

Understanding the effect of climate change is a critical economic, social and policy-relevant question

Recent literature asks:
"How will climate change affect variable X?"

- Economic growth (Dell et al., 2012)
- Economic production (Burke et al., 2015)
- Agriculture (Deschenes and Greenstone, 2012)
- Mortality (Barreca et al., 2016; Heutel et al., 2017)
- Human capital (Graff Zivin et al., 2018)
- **Electricity demand** (Davis and Gertler, 2015; Auffhammer et al., 2017; Wenz et al., 2017)

What this paper *doesn't* do:

- Does not predict *actual* future electricity demand
  - We estimate the *marginal* effect of temperature on demand
- Does not include population effects
- Does not include non-temperature related electrification
- Does not include directed technological change (supply-side)

Projected temperature changes across Canada

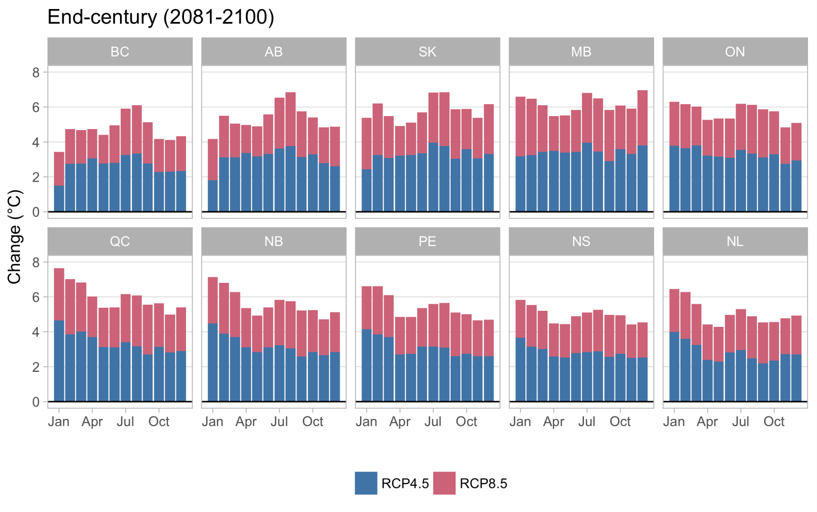

Figure 1: Temperature projections across Canada for end-century

Key Findings

- Annual Canadian electricity demand increases 3% by end-century
- Peak demand shifts to summer in most provinces
- Large increase in intraday ramping requirements across all provinces

Contributions

We build on recent literature:

1. Regional heterogeneity (Wenz et al., 2017)
2. Incorporate adaptation (Davis and Gertler, 2015)
3. Intraday shape (Auffhammer et. al., 2017)

Conceptual framework

Conceptual framework

Simple representation of electricity demand:

$$y = f(T, D(T), X) \tag{1}$$

y	Electricity demand
T	Temperature
$D(T)$	Temperature-sensitive durables, e.g. AC, electric heat, etc.
X	Non-temperature related factors

Conceptual framework

To see how demand responds to temperature, we differentiate (1) with respect to temperature:

$$\frac{dy}{dT} = \underbrace{f_T}_{\substack{\text{Direct effect} \\ \text{or} \\ \text{Intensive margin}}} + \underbrace{f_D \frac{dD}{dT}}_{\substack{\text{Indirect effect} \\ \text{or} \\ \text{Extensive margin}}} \tag{2}$$

Empirical Methodology

First, the data!

- Original dataset of hourly demand for every province in Canada for 2001-2015
    - Collected from each provincial utility and/or balancing authority
- Other data
    - Hourly temperature (2001-2015)
    - Observables (AC and electric heating penetration, residential share of demand)
    - Household level data (AC ownership, household characteristics)

Empirical strategy consists of two parts

Part 1: Estimate the relationship between temperature changes and electricity demand

Part 2: Project future demand changes using climate model temperature projections

Empirics I: Estimating temperature response functions

Three steps:

1. Estimate short run temperature response functions (f_T)
2. Condition on observables (f_T and f_D)
3. Model air condition adoption ($\frac{dD}{dT}$)

Step 1: Get short run temperature response functions

Separate regression for each province p:

$$\log(y_t^p) = \sum_b \beta_b^p T_{tb}^p + \gamma^p \theta_t + \epsilon_t^p \tag{3}$$

- y_t^p Electricity demand at datetime t in province p
- T_{tb}^p Temperature bin b at datetime t in province p
- θ_t Datetime fixed effects
- β_t^p Coefficients of interest: the effect on demand of being in temperature bin b relative to omitted bin (17-19°C) in province p

Step 1: Get short run temperature response functions

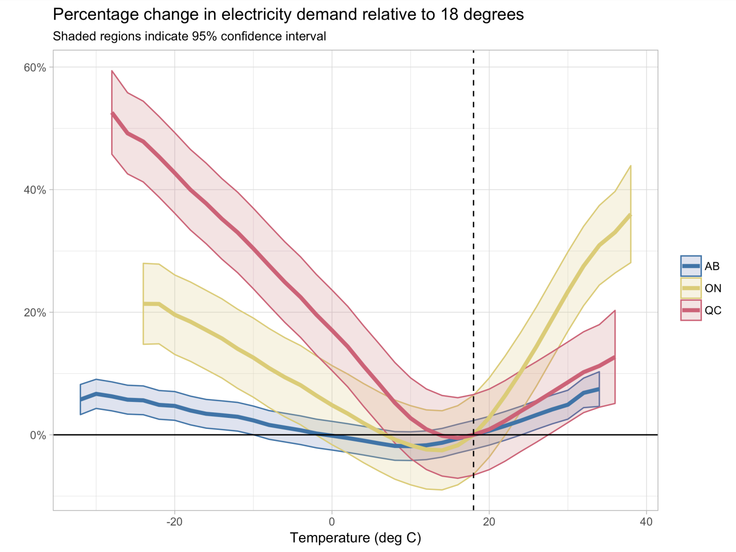

Figure 2: Temperature response functions for 3 major provinces

Step 2: Explaining heterogeneity in temperature response

We exploit variation in slopes of temperature response functions and corresponding differences in key temperature-sensitive observables:

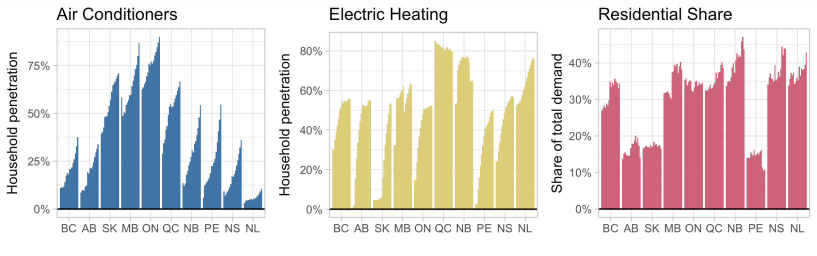

Figure 3: Key temperature-sensitive observables, 2001-2015

Step 2: Explaining heterogeneity in temperature response

New (single) regression equation becomes:

$$\log(y_t) = \delta_1 g(T_{tp}) + \delta_2 D_{tp} + \delta_3 g(T_{tp}) D_{tp} + \theta_t + \eta_p + \epsilon_t \qquad (4)$$

$g(T_{tp})$ Function of temperature at datetime t in province p (we use heating and cooling degree days instead of bins)

D_{tp} Vector of "durables" (AC, Elec Heat, Res Share)

θ_t Datetime fixed effects

η_p Province fixed effect

Step 2: Explaining heterogeneity in temperature response

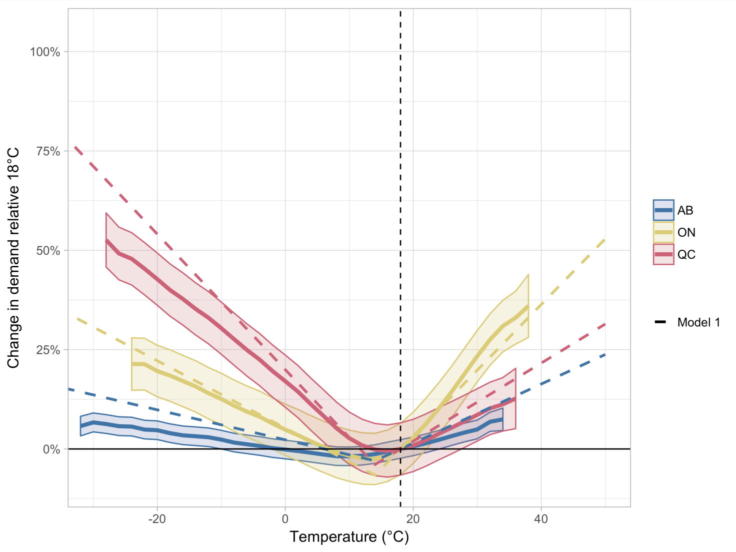

Figure 4: Temperature response functions estimated two ways

Putting it all together

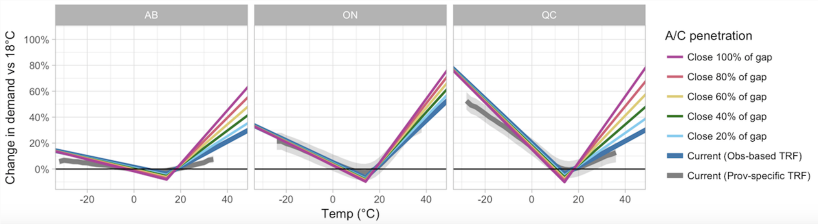

Figure 5: Temperature response at various AC penetration levels

Step 3: Estimate air conditioner adoption (dD/dT)

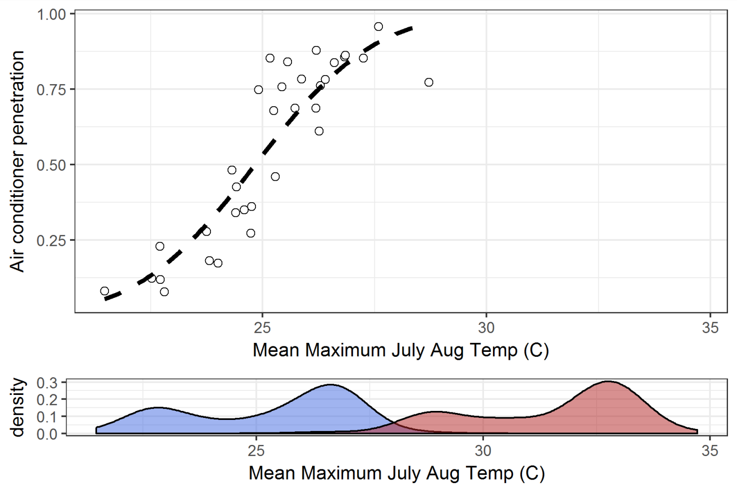

Figure 6: Air conditioner penetration as a function of climate

Projecting future demand changes

Changes to monthly average demand (Canada)

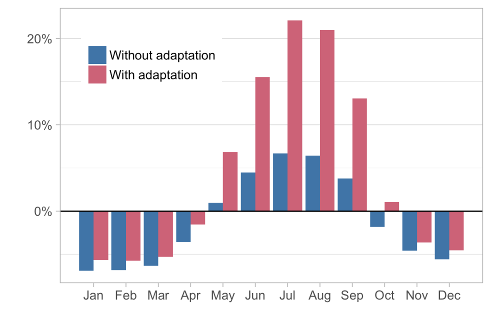

Figure 7: Monthly demand change (RCP8.5, End-century)

Changes to annual and seasonal average demand

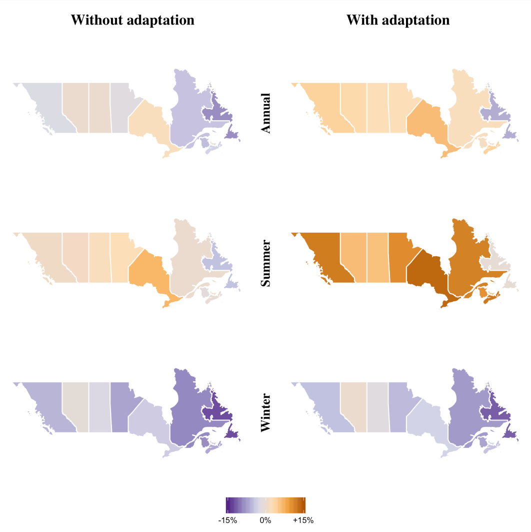

Figure 8: Average demand change (RCP8.5, End-century)

Changes to peak demand

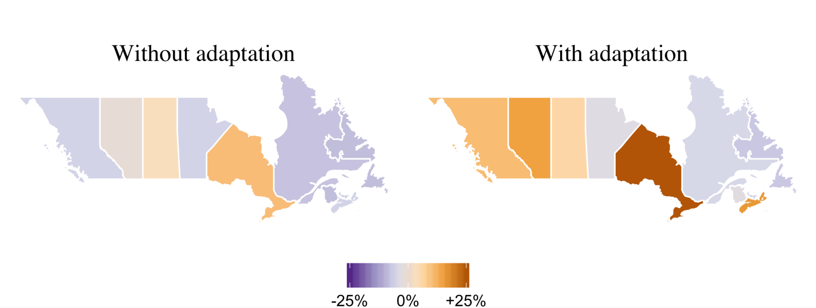

Figure 9: Peak demand change (RCP8.5, End-century)

Changes to peak season

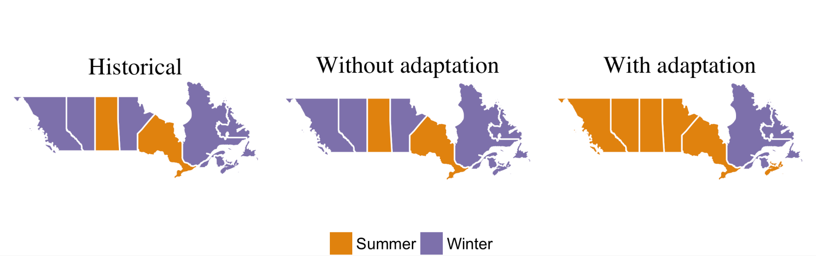

Figure 10: Peak season (RCP8.5, End-century)

Changes to intraday shape

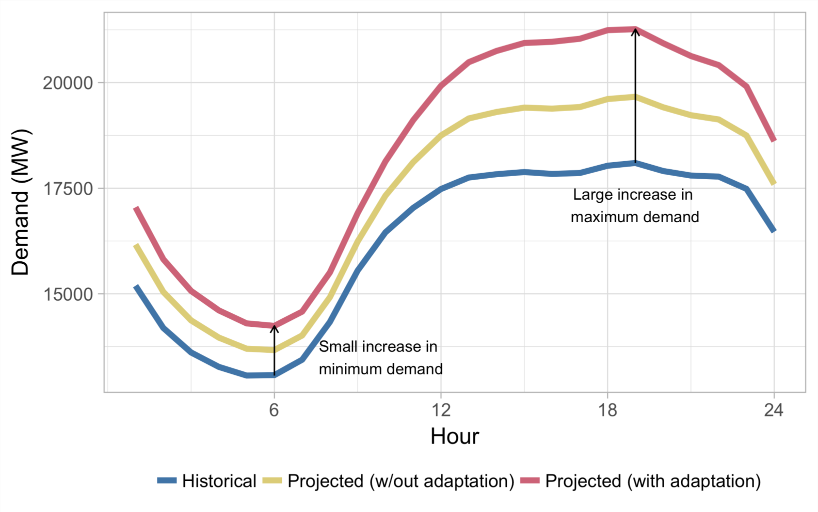

Figure 11: Intraday shape of hourly demand (Ontario) (RCP8.5, End-century)

Changes to intraday ramping requirements

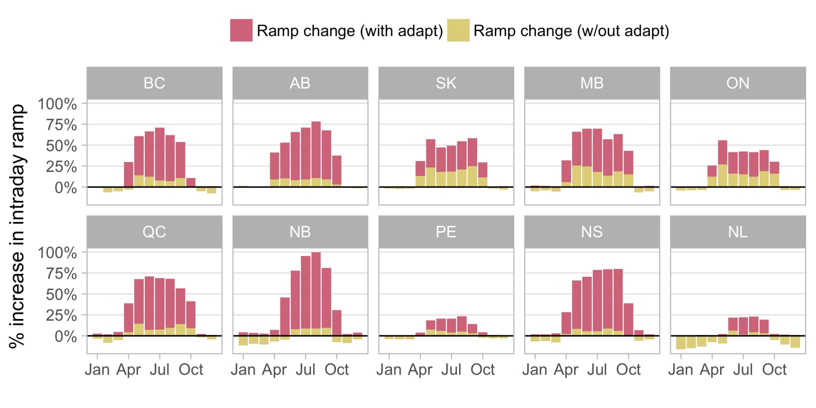

Figure 12: CHANGE IN INTRADAY MIN-TO-MAX RANGE (RCP8.5, END-CENTURY)

Conclusion

Recap of findings

- Relatively small increase in the level of demand
- Changes to peak demand vary by province
- Most provinces become summer-peaking
- Large increase in intraday ramping requirements across the provinces

Implications

- Colder countries benefit from rising temperature (in terms of reduced heating demand)
- Increase in ramping requirements exacerbates need for greater intraday flexibility coming from the supply side
- In California electricity parlance: *”Stretching the duck’s neck”*

Thank you!

blake.shaffer@ucalgary.ca