Explaining regional differences in Japan's residential energy demand: Grouped regressor effect approach

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Introduction

- Residential energy demand varies with socioeconomic and climate conditions. **How should we formulate regional differences in people's energy consumption behavior?**
- Method 1: Estimates energy demand models for all regions. Each region is characterized by a unique regression coefficient vector [1].
- Method 2: Conducts a panel-data analysis. Each region is characterized by a regional effect (an individual fixed effect).
- **Here, I propose the third method, grouped regressor effect model (GREM). The GREM classifies regions into several groups and estimates a regression coefficient vector for each group.**

log(Energy demand)
Type: electricity and fuel
Data source: ANRE

- Regional effect — Dummies for 47 prefectures (Hokkaido, Aomori, …, Okinawa)
- Time effect — Dummies for 2007, 2008, …, 2019
- log(Population) — Offset term (coefficient = 1); Data source: MIC Stat. Bureau
- **Grouped regressor effect**

$$\sum_i \left(\sum_{m=1}^{M} \beta_i^m \mathbf{1}(j \in R_i) X_{jt}^m \right)$$

X_{jt}^m	Regressor X^m in prefecture j in year t
R_i	Set of prefectures that belong to region i
$\mathbf{1}(j \in R_i)$	Indicator function that returns 1 if $j \in R_i$ and 0 otherwise
β_i^m	Coefficient of regressor X^m for region i

Regressor	Data source
log(Average household size)	MIC Stat. Bureau
log(Income level) (income tax per taxpayer)	MIC Stat. Bureau
log(Energy CPIs) (electricity, town gas, and kerosene)	MIC Stat. Bureau
CDDs (base temperatures = 18℃, 23℃, and 28℃)	JMA
HDDs (base temperatures = 8℃, 13℃, and 18℃)	JMA

1. Hyperparameter selection (LOOCV)
2. Regressor selection and parameter estimation (elastic net)
3. Model performance assessment (In-sample MAPE and CV RMSE)

Figure 1: Structure of the GREM

Methods

◆ Grouped regressor effect model (GREM)

Step 1: Classifies regions into several groups.

- I classified Japan's 47 prefectures into 10 groups: Hokkaido, Tohoku, Kanto, Hokuriku, Chubu, Kansai, Chugoku, Shikoku, Kyushu, and Okinawa.

Step 2: Constructs the GREM (Figure 1).

- **The GREM is a Gaussian linear regression model that decomposes energy demand into four effects: regional, time, population, and grouped-regressor.**
- **The effect of each regressor differs among the groups.**

Step 3: Estimates the GREM parameters.

- I estimated the model parameters using elastic net [2] and LOOCV. Unnecessary regressors were automatically removed from the model.
- R 4.2.1 and glmnet 4.1-4 [3] were used for parameter estimation.

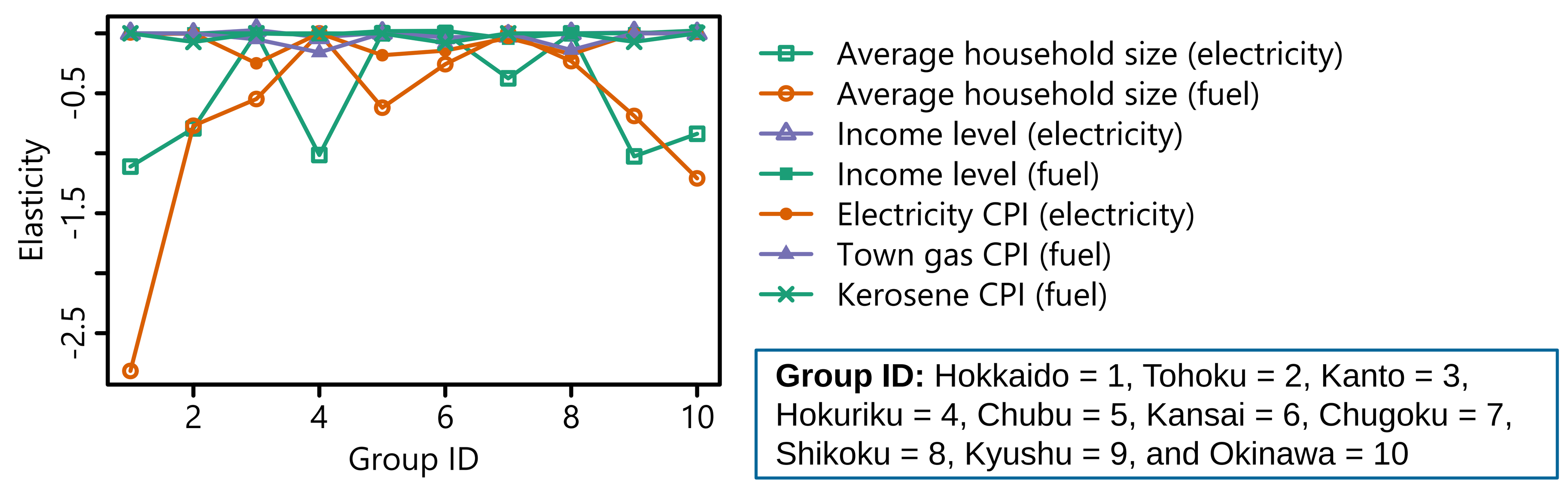
[1] Honjo and Fujii. 2014. *Reg. Sci. Pol. Pract.*, 6, 13-30.
[2] Zou and Hastie. 2005. *J. R. Stat. Soc. B*, 67, 301-320.
[3] Friedman et al. 2022. https://cran.r-project.org/web/packages/glmnet/index.html

Results

- **The estimated GREMs could explain historical changes in residential electricity and fuel demands in Japan's 47 prefectures (Table 1).**
- The regressor effects differed among the regions **(Figure 2).**
- **Figure 3** shows the temperature response functions of electricity and fuel demands per capita, calculated from the regression coefficients of CDDs and HDDs.
- **The estimation results suggest that the grouped regressor effects are necessary to explain Japan's residential energy demand.**
- A future challenge is to find the best way of classifying Japan's 47 prefectures into groups.

Table 1: Summary of the estimated models

Energy	Mixing parameter (α)	Regularization parameter (λ)	In-sample MAPE (%)	CV RMSE
Electricity	0.96	9.890e-06	4.194	0.062
Fuel	1.00	2.071e-05	5.979	0.090



Group ID: Hokkaido = 1, Tohoku = 2, Kanto = 3, Hokuriku = 4, Chubu = 5, Kansai = 6, Chugoku = 7, Shikoku = 8, Kyushu = 9, and Okinawa = 10

Figure 2: Elasticities of the grouped regressors with respect to electricity and fuel demands per capita

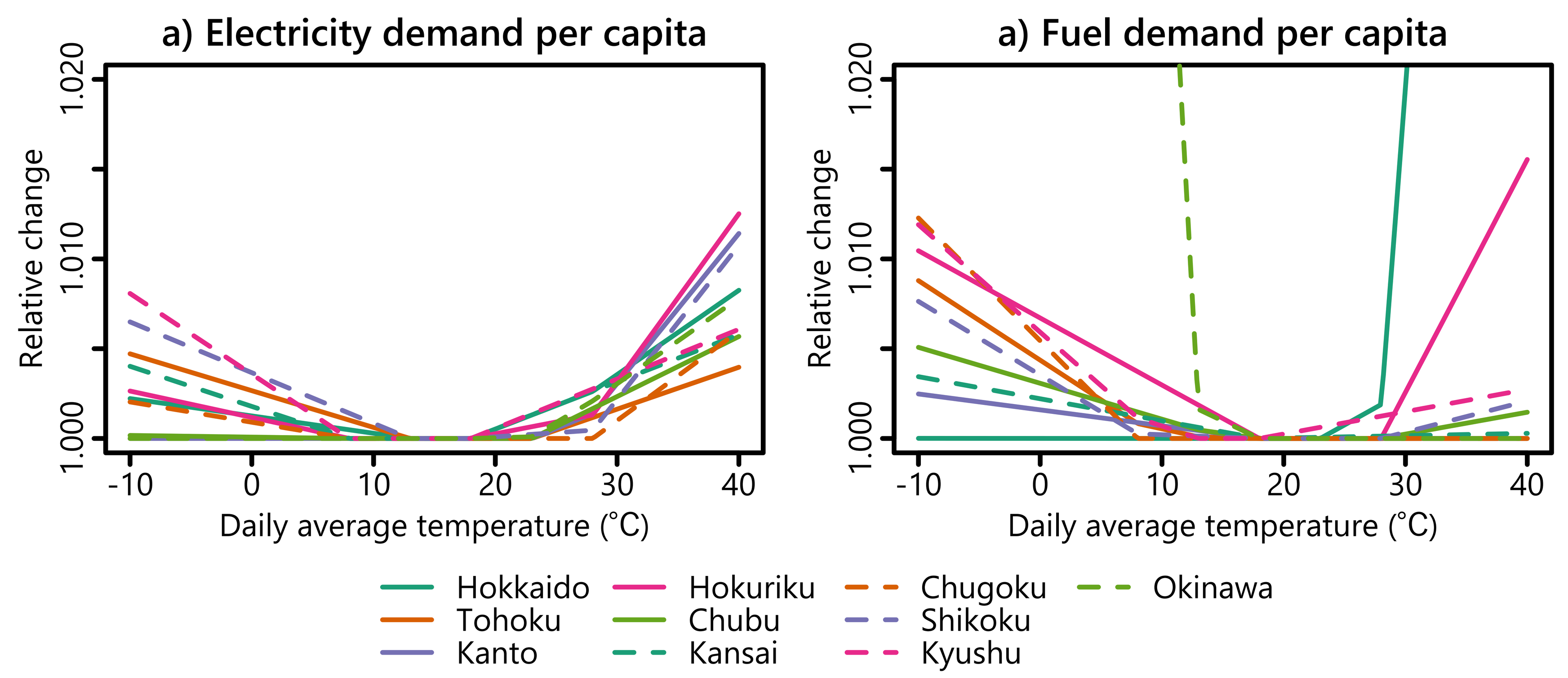


Figure 3: Temperature response functions of electricity and fuel demands per capita