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Estimating and Comparing Empirical Measures of Household Energy Insecurity

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Introduction

- Meeting basic household energy service needs is becoming exceedingly difficult for many families living in the United States (Hernández 2016)
- Energy services are functions performed inside the household that use energy (e.g. electricity, natural gas, or propane) as an input to produce a desired output (Fell 2017; Fowlie, Greenstone, and Wolfram 2018)
  - Comfortable indoor room temperatures
  - Sufficient lighting
  - Cold/hot food and beverages
- Energy service-related hardships
  - Financial constraints
  - Broken service equipment
  - Unforeseen household circumstances
- There is a need to conceptually and empirically link energy service-related hardships with felt levels of household energy insecurity (Murray and Mills 2012; Hernández 2016).



Measures of Household Energy Insecurity

Expenditure Approach	Prediction Approach	Survey Approach
Based on percentage (%) of disposable income spent on fuel/energy	Depends on amount of income required to maintain "safe" indoor room temperatures	Responses to questions related to energy-service related hardships

General Methodology

Let $n = \{1,2,\dots,N\}$ denote a set of households and s_i represent the extent of energy service-related hardships experienced be constructed as follows:

$$s_i = f(a_j) \quad \forall\, j = 1,\dots,J$$

Where a_j represents the response by household i to question j from Table 1 and $f(\ \ )$ is a general function corresponding to one of the measures applied.

Table 1. Questions from the 2015 Residential Energy Consumption Survey

SECTION L: ENERGY INSECURITY and ASSISTANCE	Question/Item j
1. In the last year, how many months did your household reduce or forego expenses for basic household necessities, such as medicine or food, in order to pay an energy bill?	Reduce
2. In the last year, has your household kept your home at a temperature that you felt was unsafe or unhealthy?	Unsafe
3. In the last year, how many months did your household received a disconnection notice, shut off notice, or non-delivery notice for an energy bill?	Notice
4. In the last year, was there ever a time your household was unable to use your main source of heat or air conditioning because you could not afford the fuel source and it was disconnected?	No Fuel
5. In the last year, was there ever a time your household was unable to use your main source of heat or air conditioning because equipment was broken, and you couldn't afford to pay to repair or replace the equipment?	HVAC
6. In the last year, has anyone in your household needed medical attention because your home was too hot or too cold?	Medical
7. About how many days over the past year, has your household gone without heat and/or air conditioning over the past year?	Days

Values of s_i are compared to an established threshold value τ to construct the **energy insecurity index** $EISINDEX_i$

Energy Insecurity Index Measures

Home Energy Assistance

Whether members of the household have applied for and received **home energy assistance**

$$s_i = \begin{cases} = 1 \text{ [Household provided a "Yes" reponse]} \\ = 0 \text{ [Otherwise]} \end{cases}$$

$$EISINDEX_i = \begin{cases} = 1 \text{ if } s_i = 1 \\ = 0 \text{ if } s_i = 0 \end{cases}$$

Expenditure Approach

Percentage of household's income spent on energy/fuel

$$s_i = \left(\frac{Annual\ Fuel\ Expenditures\ (\$)}{Median\ Annual\ Income\ (\$)} * 100\right)$$

$$EISINDEX_i = \begin{cases} = 1 \text{ if } \left(\frac{Annual\ Fuel\ Expenditures\ (\$)}{Median\ Annual\ Income\ (\$)} * 100\right) \geq 10 \text{ or } 6 \\ = 0 \text{ if } \left(\frac{Annual\ Fuel\ Expenditures\ (\$)}{Median\ Annual\ Income\ (\$)} * 100\right) < 10 \text{ or } 6 \end{cases}$$

Cluster Analysis

Observations **are divided into groups** based on pattern of responses to questions in Table 1

$$s_i = \frac{w+z}{w+x+y+z}$$

- w is the number of questions for which individual households i and j both responded in the affirmative
- z is the number of questions for which individual households i and j both did not respond in the affirmative
- x is the number of questions in which household i responded in the affirmative but household j did not
- y is the number of questions in which household j responded in the affirmative but household i did not

$$EISINDEX_i = \begin{cases} 1 \\ 2 \\ 3 \\ 4 \end{cases}$$

based on the proportion of matches between s_i and s_j

Principal Components Analysis (PCA)

Link responses to questions together to measure outcome variable of interest

$$s_i = \widehat{w}_{11}a_1 + \widehat{w}_{12}a_2 + \cdots + \widehat{w}_{17}a_7$$

Construct energy insecurity index measures based on different chosen values of the threshold τ. Consider threshold value of $\tau = 0$

$$EISINDEX_i = \begin{cases} = 0 \ \ if \ \ s_i = 0 \\ = 1 \ \ if\ s_i > 0 \end{cases}$$

$$EISINDEX_i = \begin{cases} = 0 \text{ if } s_i = 0 \\ = (s_i - 0) \text{ if } s_i > 0 \end{cases}$$

Separate **energy secure households from energy insecure** households based on value of s_i received. Develop two index measures from PCA results

Dichotomous Rasch Model

Type of **item response theory (IRT)** model

$$Prob(I_{ij} = 1 | \alpha_i, \theta_j) = \frac{\exp(\alpha_i - \theta_j)}{1 + \exp(\alpha_i - \theta_j)}$$

Probability a household responds affirmatively to question $I_{ij} = 1$ is conditional on the household's **underlying latent** energy insecurity status, α_i, and the individual question's level of **severity** θ_j. Values for s_i based on number of household responses to **increasingly severe** questions. Classify households into different energy insecurity groups based on the distance between the raw energy insecurity score the household receives and the value of the threshold τ

$$EISINDEX_i = \begin{cases} = 0 \text{ if } \ s_i \ \leq \tau \\ = \ (s_i - \tau) \text{ if } s_i > \tau \end{cases}$$

Normalized energy insecurity index

$$d_i = \frac{s_i - \tau}{z - \tau} \text{ if } s_i > \tau\ ;\ d_i = 0 \text{ if } s_i \leq \tau$$

- d is denotes the degree of energy insecurity suffered by the group of all households N (Gundersen 2008; Balistreri 2016)
- z is the maximum possible energy insecurity score able to be received by a household from the application of the model
- All other terms are as defined previously

Energy Insecurity Index Results

Home Energy Assistance Results

Figure 1. Energy Insecurity Index Results Using the Receipt of Home Energy Assistance to Measure Energy Insecurity

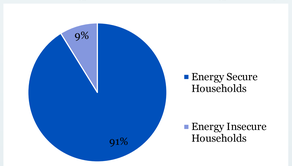
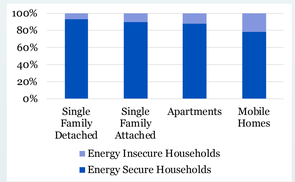


Figure 2. Energy Insecurity Index Results by Household Type Using the Receipt of Home Energy Assistance



Expenditure Approach Results

Figure 3. Expenditure Approach Results Using 6% of Disposable Income as Threshold

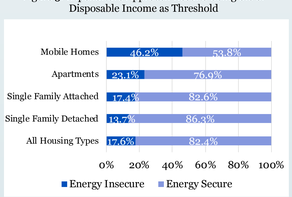
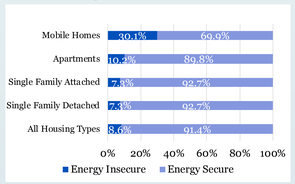


Figure 4. Expenditure Approach Results Using 10% of Disposable Income as Threshold



Cluster Analysis Results

Table 2. Cluster Analysis Results and Means of Responses to Demographic Household Questions

Energy Insecurity Groups	Number of Households (% of Households)	Median Income	Ownership	Employed	Members	Children	Education
High Energy Secure (Group 2)	4,832 (85%)	66,916	0.72	0.49	2.52	0.56	3.22
		(42,998)	(0.45)	(0.50)	(1.40)	(1.01)	(1.14)
Marginally Energy Secure (Group 3)	634 (11%)	36,293	0.48	0.41	2.81	0.80	2.60
		(28,815)	(0.50)	(0.49)	(1.49)	(1.13)	(1.00)
Low Energy Secure (Group 1)	144 (3%)	41,458	0.61	0.44	3.06	0.92	2.76
		(34,152)	(0.49)	(0.50)	(1.68)	(1.18)	(1.08)
Very Low Energy Secure (Group 4)	76 (1%)	30,526	0.61	0.37	3.25	1.09	2.33
		(23,526)	(0.49)	(0.49)	(1.79)	(1.39)	(1.06)
Total	N=5,686						

Energy Insecurity Index Results Continued..

Principal Components Analysis (PCA) Results

Figure 5. Energy-Service Related Hardships Scores Produced by the Application of PCA

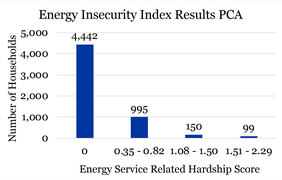


Table 3. Energy Insecurity Index Results from the Application of PCA

Energy Insecurity Status	Number of Households
Energy Secure	4,442 (78.3%)
Low Energy Insecurity	995 (17.4%)
Marginal Energy Insecurity	150 (2.6%)
High Energy Insecurity	99 (1.7%)
Total	5,686

Dichotomous Rasch Model Results

Table 4. Dichotomous Rasch Model Results

Questions Responded Affirmatively To	s_i	d_i	No. of Households	%	$EISINDEX_i$	Classification
0	0	0	4,442	90.5%	1	Low Energy Insecurity
1	3.08	0	705			
2	4.38	0.40	290	9.0%	2	Marginally Energy Insecurity
3	4.44	0.42	146			
4	4.48	0.43	77			
5	5.65	0.79	22	0.4%	3	High Energy Insecurity
6	6.20	0.96	4	<0.1%	4	Very High Energy Insecurity
7	6.34	1	0			
Observations	N = 5,686					

More affirmative responses indicate higher levels of felt energy insecurity.

Validity of Energy Insecurity Index Results

Examination of the validity of the different indices produced indicated the energy insecurity index produced from the **dichotomous Rasch model** are preferred

- **Construct validity**: the questions from Section L of the 2015 RECS (see Table 1) used to construct the index were developed over multiple iterations of the survey
- **Content validity**: Positive responses to questions provide an accurate representation of the household's inability to maintain adequate access to a sufficient, safe, and affordable energy supply to meet daily energy service needs
- **Convergent validity:** Households who identified as energy insecure are the same households who identified as energy insecure following the other four index measures

Dichotomous Rasch model results are also correlated with household level characteristics (e.g., income, education, home ownership, race) as expected from the literature (Drehobl and Ross 2016)

Conclusions

- Using the provision of home energy assistance or the expenditure approach to measure the extent of energy insecurity only reveals information related to the household's ability to afford household energy services.
- Cluster analysis, PCA, and the dichotomous Rasch model are applied to questions in Table 1, which reference sufficiency, safety, and affordably of a household's energy supply to provide energy services
- The index results from the dichotomous Rasch model were not only highly correlated with the other index measures but also correlated with other household characteristics as expected
- Results produced from the **dichotomous Rasch model** provided the most consistent and accurate representation of felt levels of household energy insecurity.

Acknowledgements

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