Energy Conservation in Homes: What are the Implications for Water?

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Central Research Questions

- Do homeowners in more energy efficiency homes:
  - Drive more or less? How much?
  - Use more or less water? How much?

- How does consistent (correlated) technical efficiency change across end uses affect energy use, water use, and energy externalities?

- In other words, does the rebound effect increase or decrease marginally with consistent efficiency change?

Multiple Perspectives on Technical Efficiency

What happens if you double the efficiency of your air conditioner?

The technologist says, "You use half the energy."

The economist says, "You turn down the thermostat."

The social scientist says, "Who made the decision?"

Economic/Behavioral Responses to Efficiency

- ***Direct rebound:*** *Use more of the more efficient service*
  - Example: drive more with a more fuel efficient car

- ***Indirect rebound:*** *Re-spend savings on production*
  - *Example: Savings from efficient lighting spend on 2nd refrigerator*

- **Economy-wide rebound:** *More efficient production increases economic growth*
  - *Example: A more efficient steam engine increases production*

Conventional, single-service model

- Definition of technical efficiency, $S_i = E_i\ \varepsilon_i$

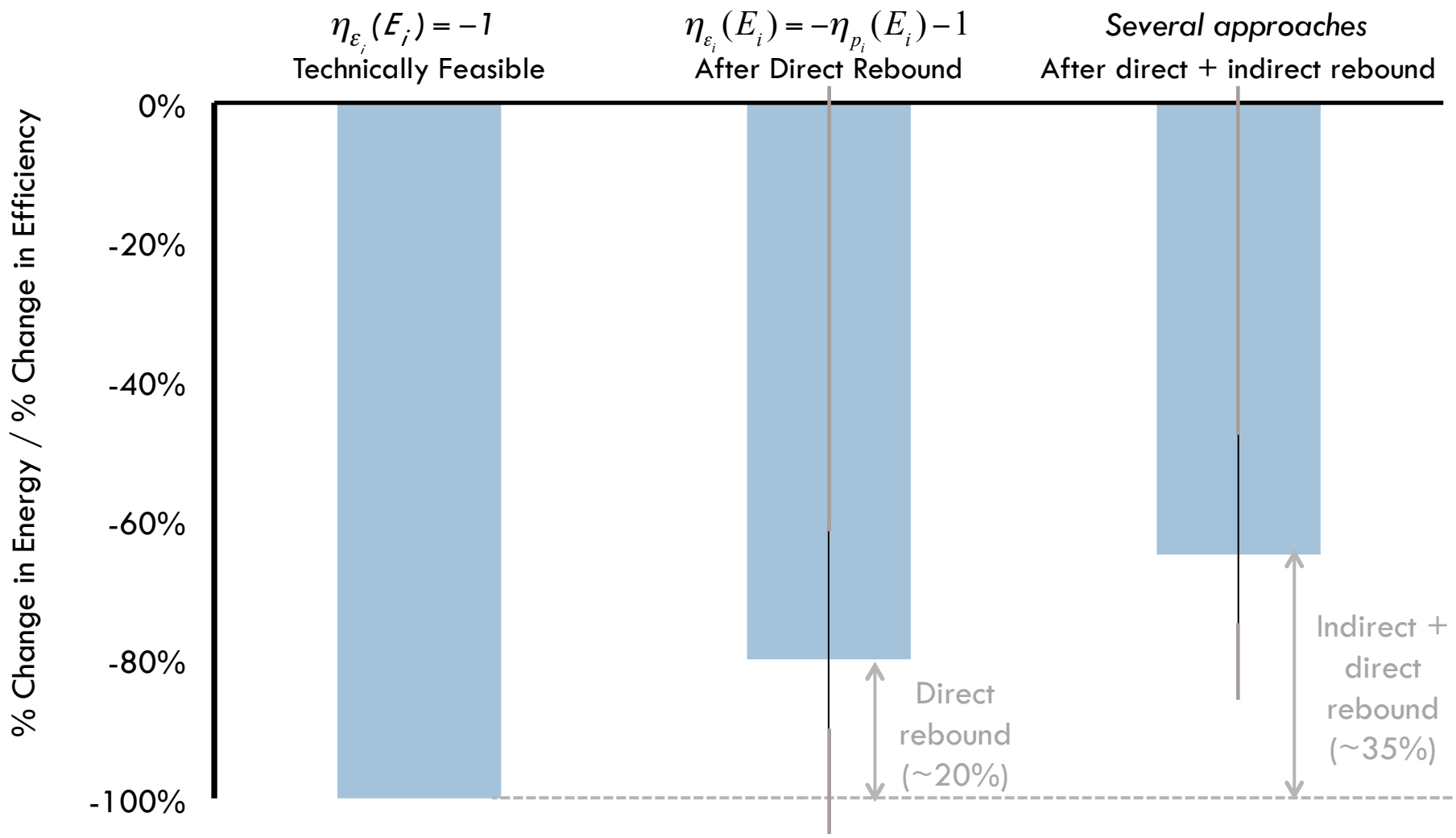
$$\frac{\partial E}{\partial \varepsilon}\frac{\varepsilon}{E} = \frac{\partial S/\partial \varepsilon \varepsilon - S}{\varepsilon^2}\frac{\varepsilon}{E} = \frac{\partial S/\partial \varepsilon \varepsilon - S}{\varepsilon^2}\frac{\varepsilon}{S/\varepsilon} = \eta_{\varepsilon_i}(E_i) = \eta_{\varepsilon_i}(S_i) - 1$$

$$\eta_{\varepsilon_i}(E_i) = \eta_{\varepsilon_i}(S_i) - 1$$

$$\eta_{\varepsilon_i}(E_i) = -\eta_{p_i}(E_i) - 1$$

- Can similarly be derived using neoclassical economic production functions

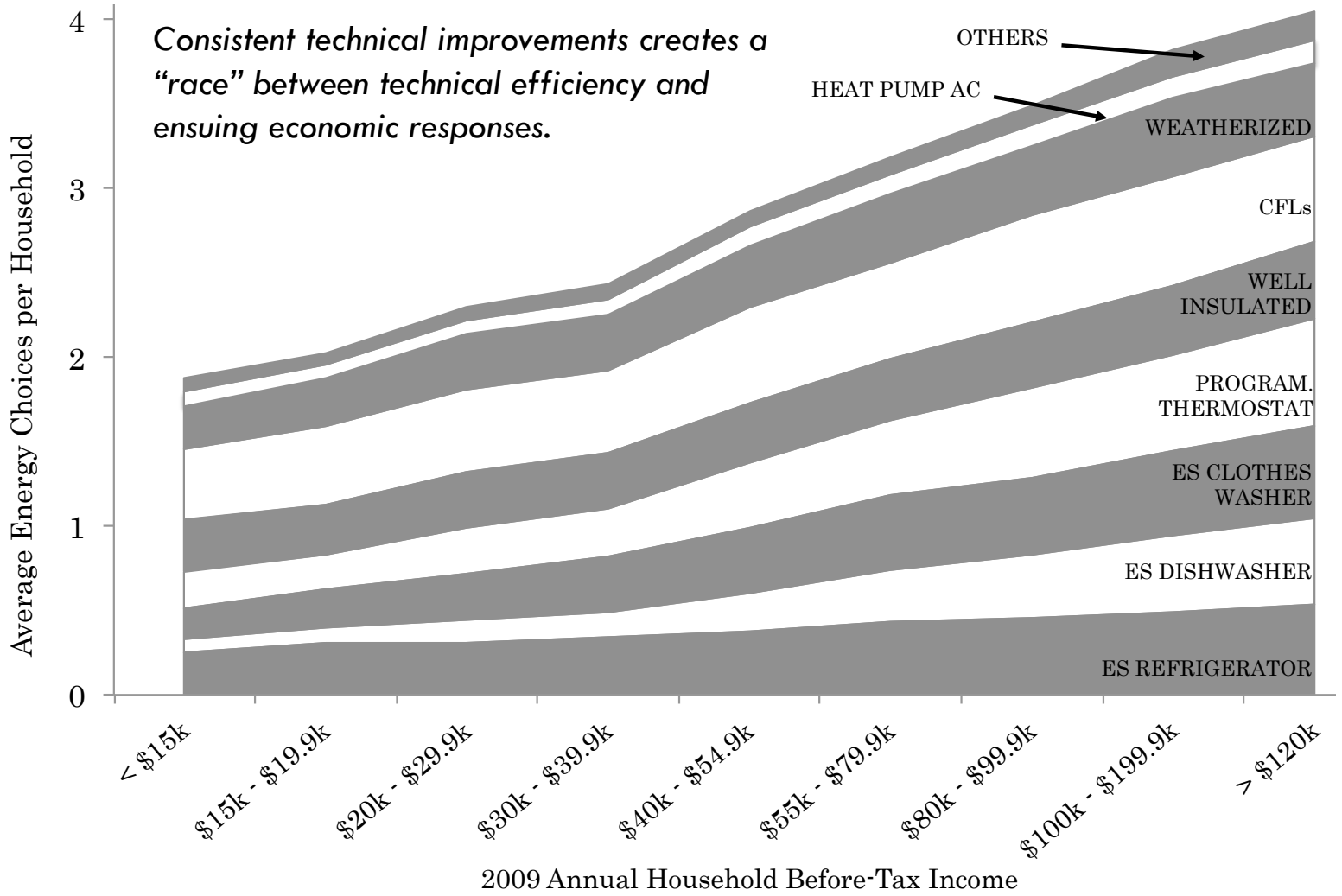
Magnitude of Rebound Debated



Rebound empirical estimates vary widely

- Variation in income and shares (expected)
- Variation in methods
- *Short- versus long-run responses*
- *Models treat all households homogeneously*
- *Models assume technical change for only one services*

Rebound Implications of Consistent Technical Improvement?



Two-service model

- Services i and j with distinct but correlated efficiency changes

$$\frac{\partial E_i}{\partial \varepsilon_i}\frac{\varepsilon_i}{E_i} = \left(\frac{\partial E_i}{\partial \varepsilon_i} + \frac{\partial E_i}{\partial \varepsilon_w}\frac{\partial \varepsilon_w}{\partial \varepsilon_i}\right)\frac{\varepsilon_i}{E_i} = \frac{\partial E_i}{\partial \varepsilon_i}\frac{\varepsilon_i}{E_i} + \frac{\partial E_i}{\partial \varepsilon_w}\frac{\partial \varepsilon_w}{\partial \varepsilon_i}\frac{\varepsilon_i}{E_i}\frac{\varepsilon_w}{\varepsilon_w}\frac{\varepsilon_i}{\varepsilon_i}$$

$$\eta_{\varepsilon_i,c}(E_i) = \eta_{\varepsilon_i}(E_i) + \eta_{\varepsilon_j}(E_i)\eta_{\varepsilon_i}(\varepsilon_j)$$

$$\eta_{\varepsilon_j,c}(E_j) = \eta_{\varepsilon_j}(E_j) + \eta_{\varepsilon_i}(E_j)\eta_{\varepsilon_j}(\varepsilon_i)$$

CES Production Functions to Model Elasticities

$$\eta_{\varepsilon_i,c}(E_i) = -1$$ Technical change

$$-\eta_{p_i}(E_i)$$ Direct rebound

$$(1-\sigma)\frac{p_j E_j}{M}\eta_i(\varepsilon_j)$$ Indirect rebound from consistent technical change in j

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$$\eta_{\varepsilon_i,c}(E_i) = -1 \; -\eta_{p_i}(E_i) + (1-\sigma)\frac{p_j E_j}{M}\eta_i(\varepsilon_j)$$

Or as structural format

$$\eta_{\varepsilon_i,c}(E_i) = (1-\sigma)\left(1-\frac{p_i E_i}{M}\right) + (1-\sigma)\frac{p_j E_j}{M}\eta_i(\varepsilon_j)$$

Two Energy Services, i + j

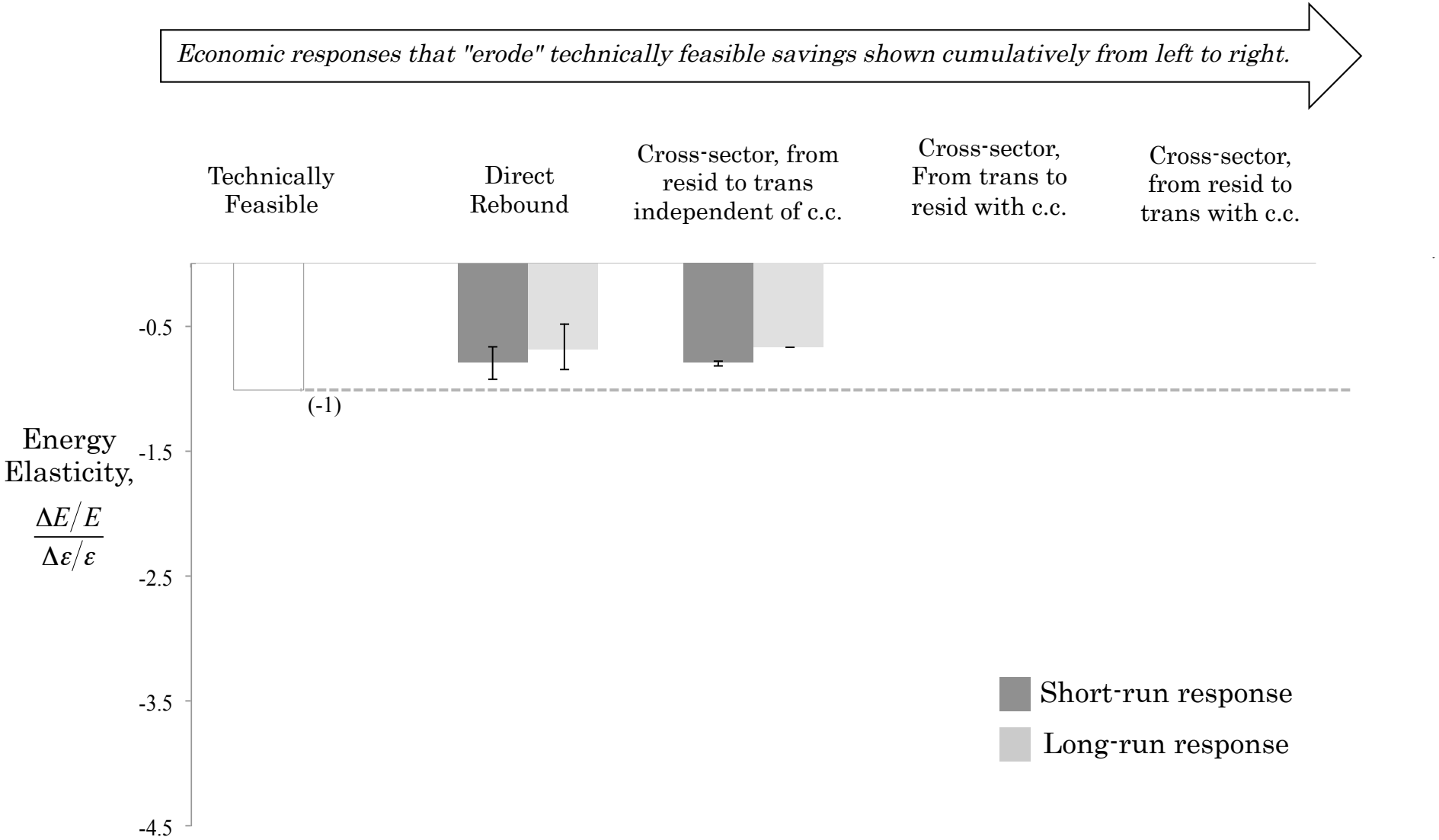
$$\eta_{\varepsilon_i,c}(E_i+E_j) = \underbrace{-\left(\frac{E_j}{E}+\eta_{\varepsilon_i}(\varepsilon_j)\frac{E_j}{E}\right)}_{\text{technical efficiency}} + \overbrace{\eta_{\varepsilon_i}(E_j)\frac{E_j}{E}}^{\substack{\text{responding on j,}\\ \text{independ. of technical}\\ \text{change for i}}} + \overbrace{[\eta_{\varepsilon_i}(E_j)+1]\frac{E_j}{E}}^{\text{direct rebound}} +$$

$$\overbrace{\eta_{\varepsilon_i}(\varepsilon_j)\eta_{\varepsilon_i}(E_i)\frac{E_i}{E}}^{\substack{\text{responding on i}\\ \text{from consistent}\\ \text{efficiency change to j}}} + \overbrace{\eta_{\varepsilon_i}(\varepsilon_j)\left[\eta_{\varepsilon_i}(E_j)+1\right]\frac{E_j}{E}}^{\text{responding on j from technical change in i}}$$

Rebound Across Sectors: From residential to the transportation sector

- Owners of more efficient homes may re-spend monetary savings on driving. How much?
- What if homeowner also purchases more efficient vehicle, e.g., makes consistent technology choices?
- On average, would rebound be different if a near-zero energy homes were built in suburbs versus urban core?
- How does consistent, but perhaps, disproportionate efficiency change effect energy externalities (e.g., carbon and water)?

Cross-Sector Rebound: From Residential to Transportation Sector



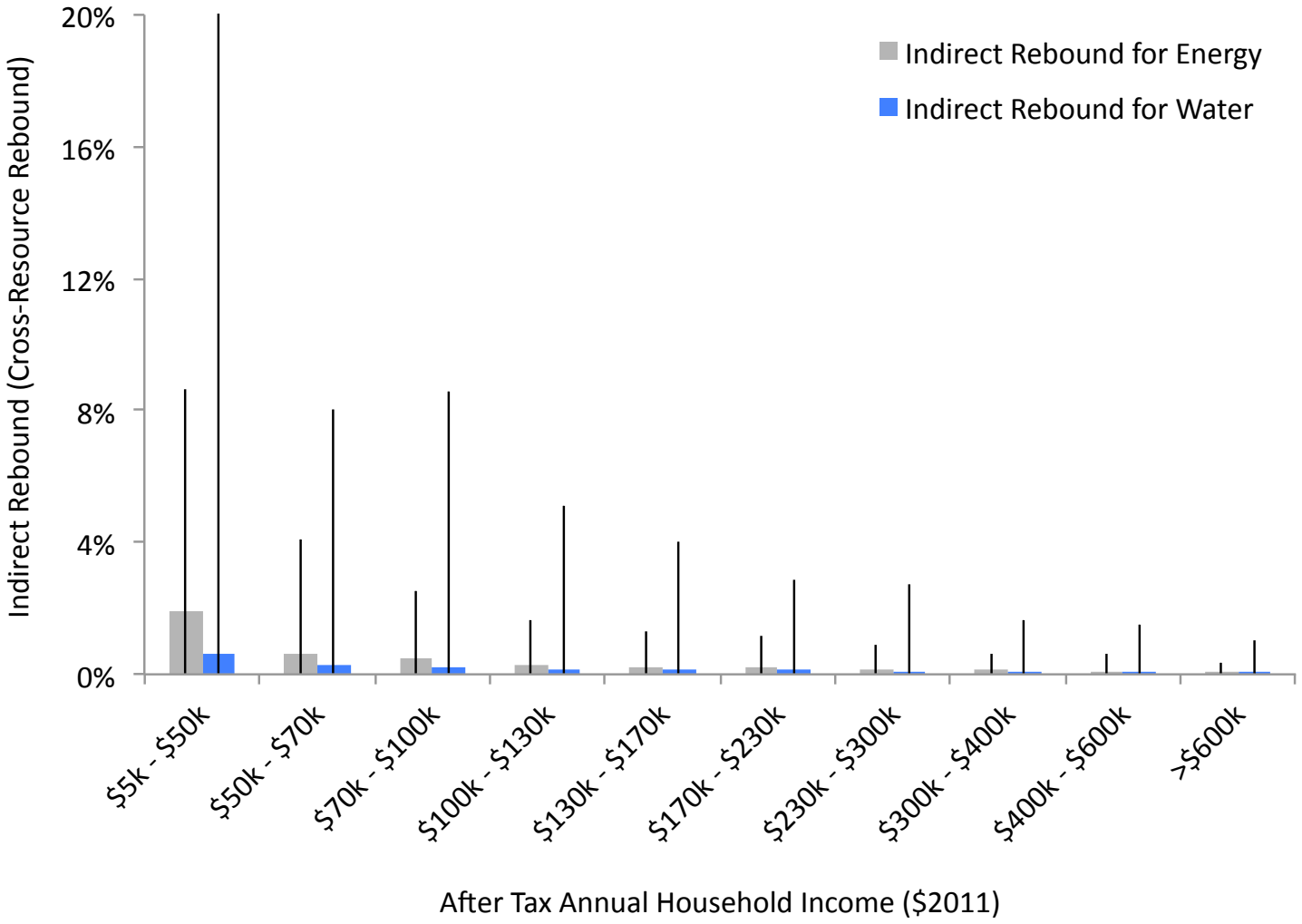
Energy (E) and water services (W)

- For energy (E) and water services (W)

$$\eta_{\varepsilon_E,c}(E) = \eta_{\varepsilon_E}(E) + \eta_{\varepsilon_W}(E_E)\eta_{\varepsilon_E}(\varepsilon_W)$$

$$\eta_{\varepsilon_W,c}(W) = \eta_{\varepsilon_W}(W) + \eta_{\varepsilon_E}(W)\eta_{\varepsilon_W}(\varepsilon_E)$$

Cross-Resource Rebound



Qualitative Findings

- Proportional efficiency improvements across ALL energy and water end-uses is needed reduce indirect rebound
- Disproportionate efficiency changes can significantly erode the net technical efficiency gains
- The background rate of technical change exogenous to households influences rebound (e.g., Federal efficiency standards)
- Disproportionate efficiency changes can "push" consumption towards different energy sources (and respective energy externalities)
- Efficiency improvements for existing end uses are limited by thermodynamics, but economic responses are now
- Long-run response are critical given long-lived service life of durable goods and propensity for new energy services

Some Anecdotes

- From most recent national survey of residential energy use

  *Although some appliances that are subject to federal efficiency standards, such as refrigerators and clothes washers, have become more efficient, the increased number of devices that consume energy in homes has offset these efficiency gains. (*EIA 2012)

- An early industrialist claims a more efficient steam engine would solve 19th century energy and economic problems. Do you believe it?

- How would we re-spend our savings if we all lived in net-zero energy homes? Implications for material consumption
  - Water (currently research project)
  - Rare materials

Next Steps

- Estimate effect on energy externalities using environmental life cycle assessment
- Characterize end-uses and contexts where consistent efficiency change least and most "matters"

Thanks

- Questions :: Comments
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