Applications with Little or No Rebound

Digitalization and the Rebound Effect – HS2019

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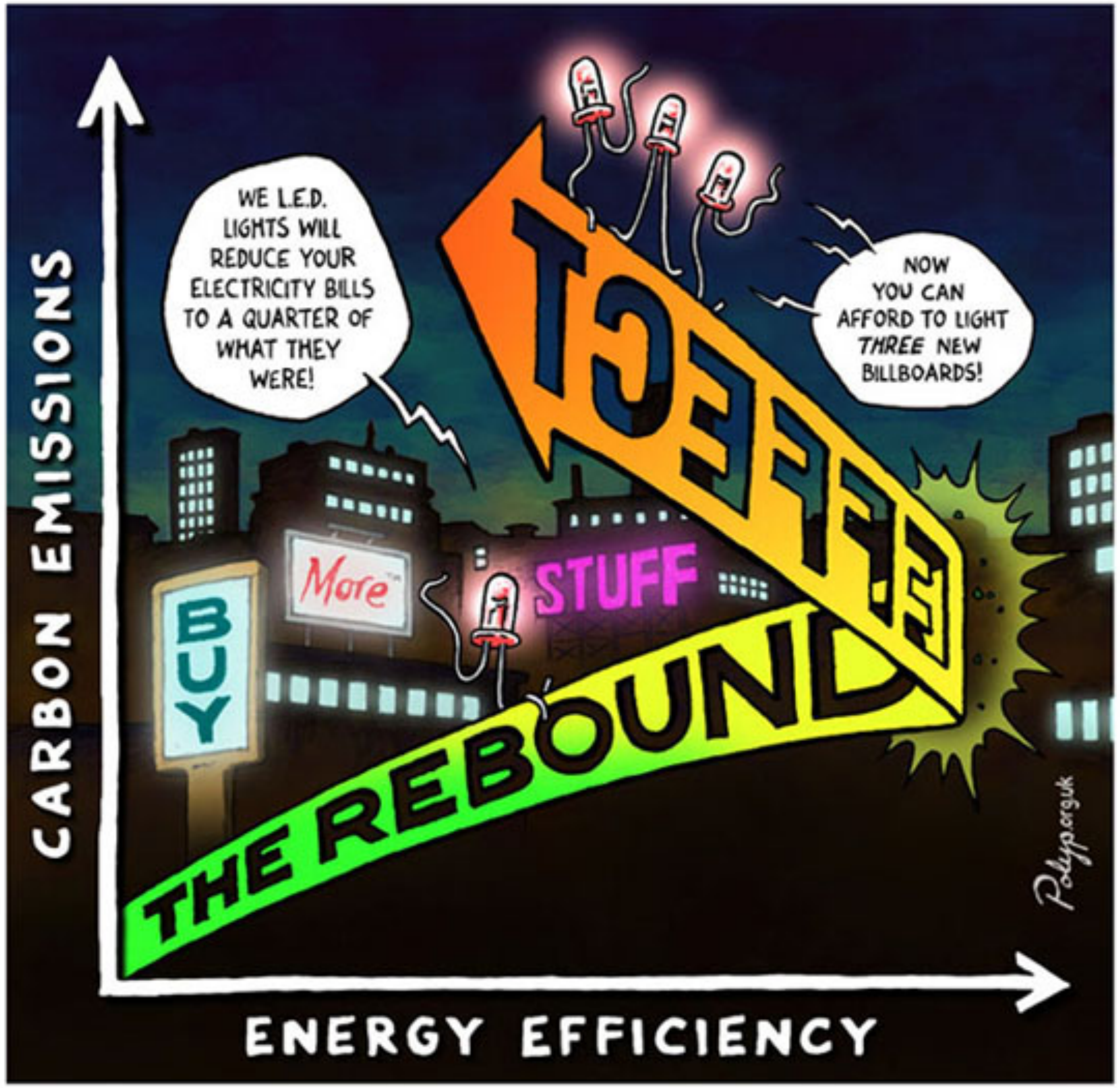

Goal: No Rebound!

→ after an efficiency improvement to produce one unit, price will not decrease and therefore demand will not increase

Source: https://www.thegwpf.com/green-madness-energy-efficient-led-lighting-increases-energy-consumption-light-pollution

Case Studies

- Urban Natural Gas Pipeline Leaks 🇺🇸
- Real-Time Feedback for Resource Conservation 🇨🇭
- Smart Vending Machines 🇯🇵

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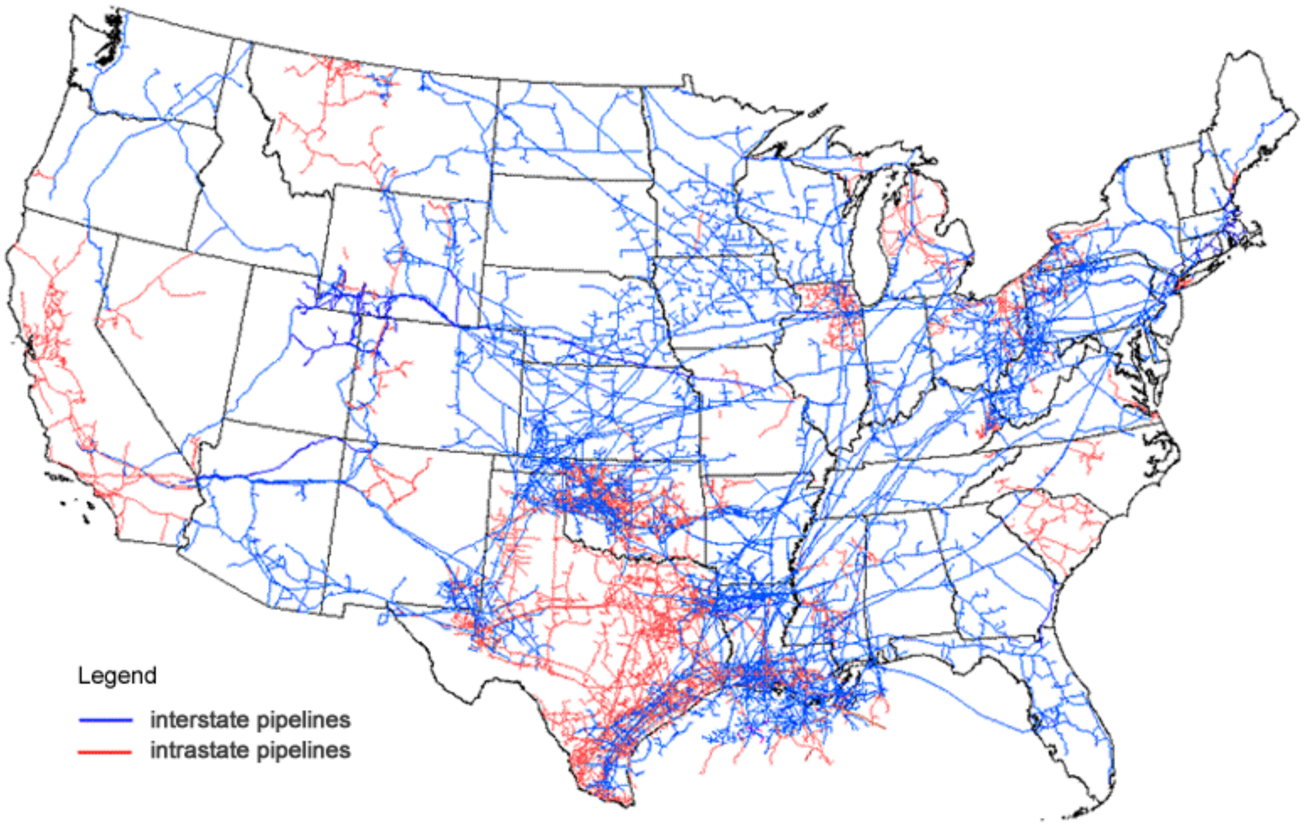
Natural Gas Pipelines in the US

Map of U.S. interstate and intrastate natural gas pipelines



Source: U.S. Energy Information Administration, *About U.S. Natural Gas Pipelines*

Problem: Leakage of Methane (CH_4)

- Legacy pipelines are prone to leakage
- Locations and magnitudes of leaks in pipelines are not well-known
- Accelerated pipeline replacement programs (APRP)
- **Goal:** quantify leaks to facilitate prioritized repair to minimize greenhouse gas emissions

Source: https://urbanomnibus.net/2018/09/gas-flows-below/

Method

- Leak size can be estimated by measuring CH_4 concentration in the air
- Partnership with Google Street View
- Analyzer reading CH_4 concentration installed on cars

Source: Fischer et al., 2017

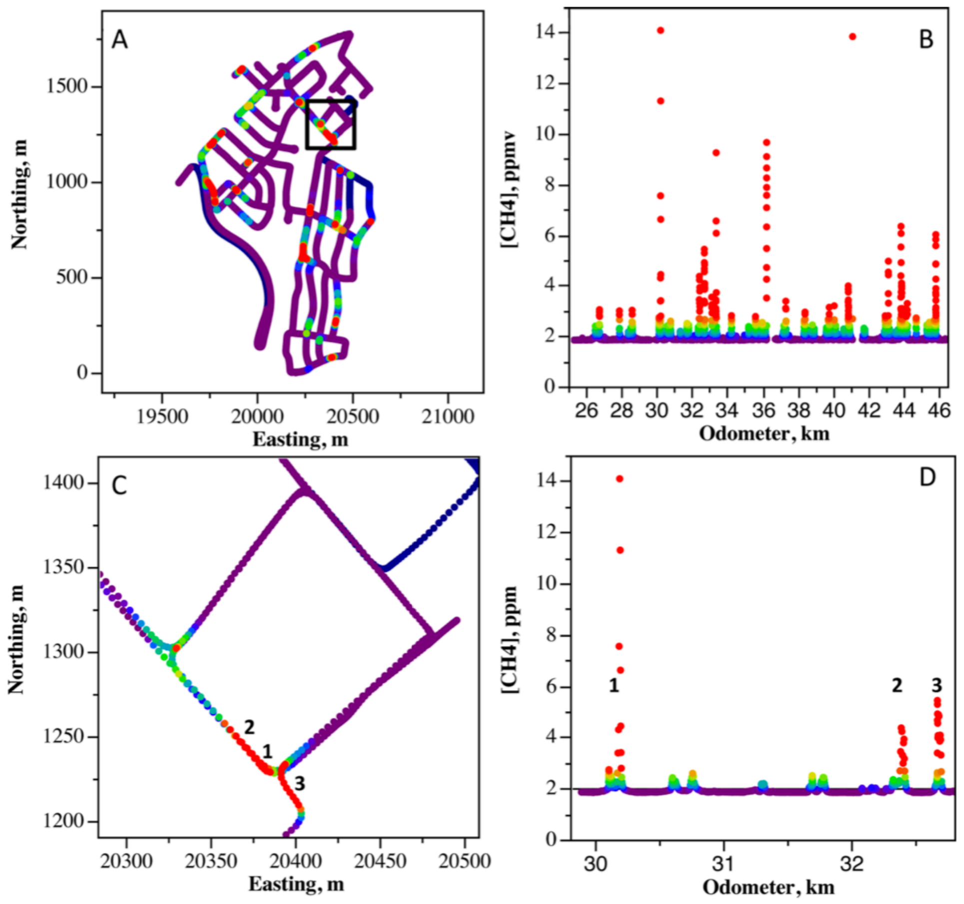
Study

- Control Study:
  - Controlled releases of CH_4: 2, 10, 20, 40 L/min
  - Distances of emission points and car: 5, 10, 20, 40 m
- Experiment constraints to screen out false positives:
  - Defined background methane concentrations
  - Methane concentrations must be persistently elevated over time
  - No data with speed >70 km/h
  - Exclude leaks with too high CH_4 concentration (areas near landfills)

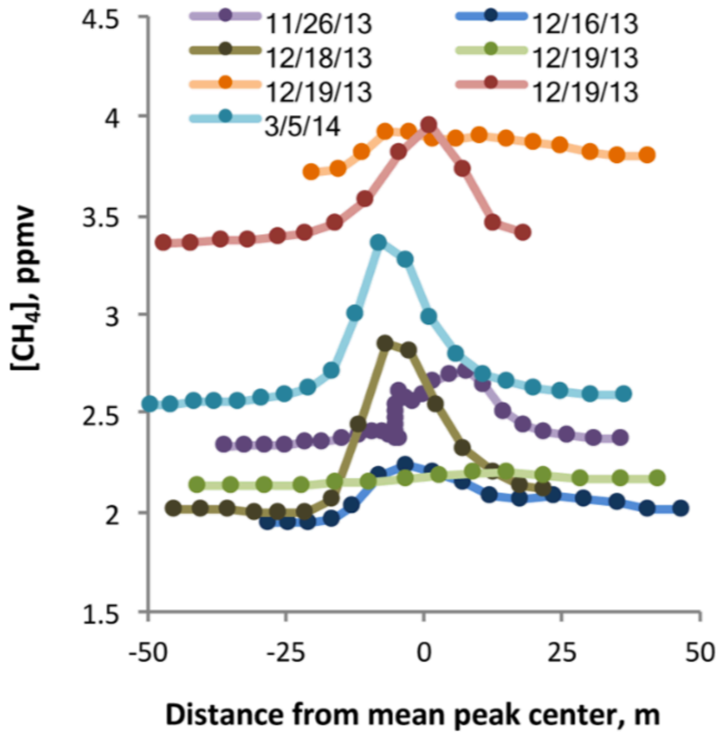
Results: Control Study

- Leak rate categories:
  - Small: < 6 L/min
  - Medium: 6-40 L/min
  - High: > 40 L/min
- When driving ≤20m at all release rates, CH_4 readings were 10% higher than background → method works

Results: Example Patterns



Example data shown as maps and as a function of distance traveled by the vehicle. *Source: Fischer et al., 2017*

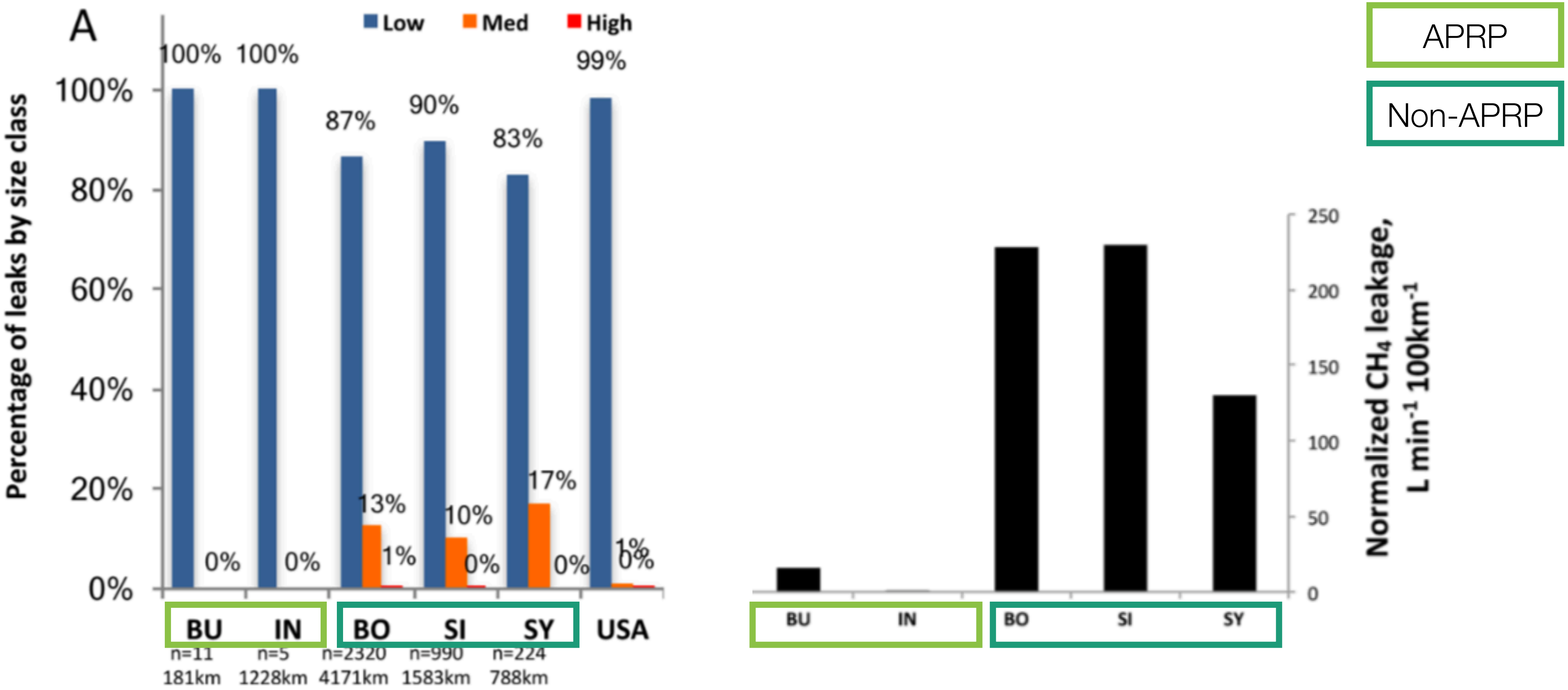


Spatial repeatability of data gathered
Source: Fischer et al., 2017

Cumulative Leak Rates

- City-wide leak rate by averaging individual leak rate estimates and summing across all leaks
- **Results:**
  - non-APRP cities: 2 L/min CH_4 per km
  - APRP cities: 0.08 L/min per km.
  - Boston: 1300 tons CH_4 per year

Results: Comparison of Cities



Comparison of leak frequencies and magnitudes in study cities (BU) Burlington, VT, (IN) Indianapolis, IN, (BO) Boston, MA, (SI) Staten Island, NY, (SY) Syracuse, NY.

Source: Fischer et al., 2017

Conclusion

- APRP projects achieve their goals
- In non-APRP cities, repairs of the largest 8% of leaks would reduce natural gas emissions by 30%
- Rebound Effect?
    - Natural gas does not get cheaper with fixed leaks → No Rebound!

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Experiment

- 4-minute shower: 45 liters of hot water → 2.6 kWh to heat up
- 1 kWh for lighting per day

Salience Bias

- Salience bias in the moment of decision-making attributes to the discrepancy between peoples‘ aspirations and their daily behavior

→ Goal: Correct salience bias

- Energy use is particularly prone to salience bias
- Target activity: Showering

Existing Measures to Reduce Energy Use

- Home energy reports: – 0.5%
- Smart metering about aggregate electricity consumption: – 3.5%
- Price increases
- Information campaigns

→ We need something better!

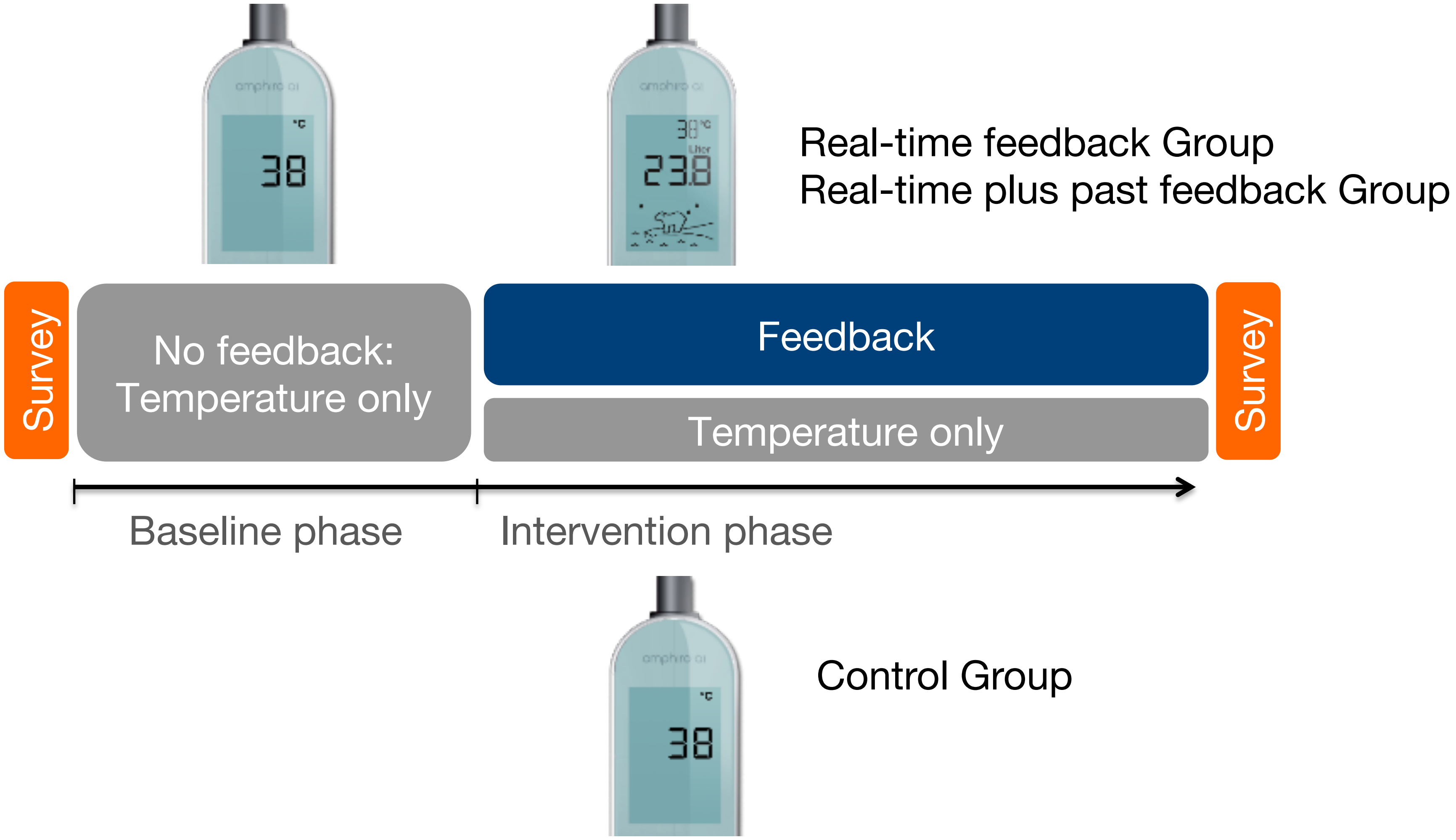
Solution: Specific real-time feedback

Experimental Setup

- Smart shower meter calculates lower bound of energy use by: $Q = m \cdot c \cdot \Delta T$
- Experimental conditions:
  1) Real-time feedback
  2) Real-time plus past feedback
  3) Control

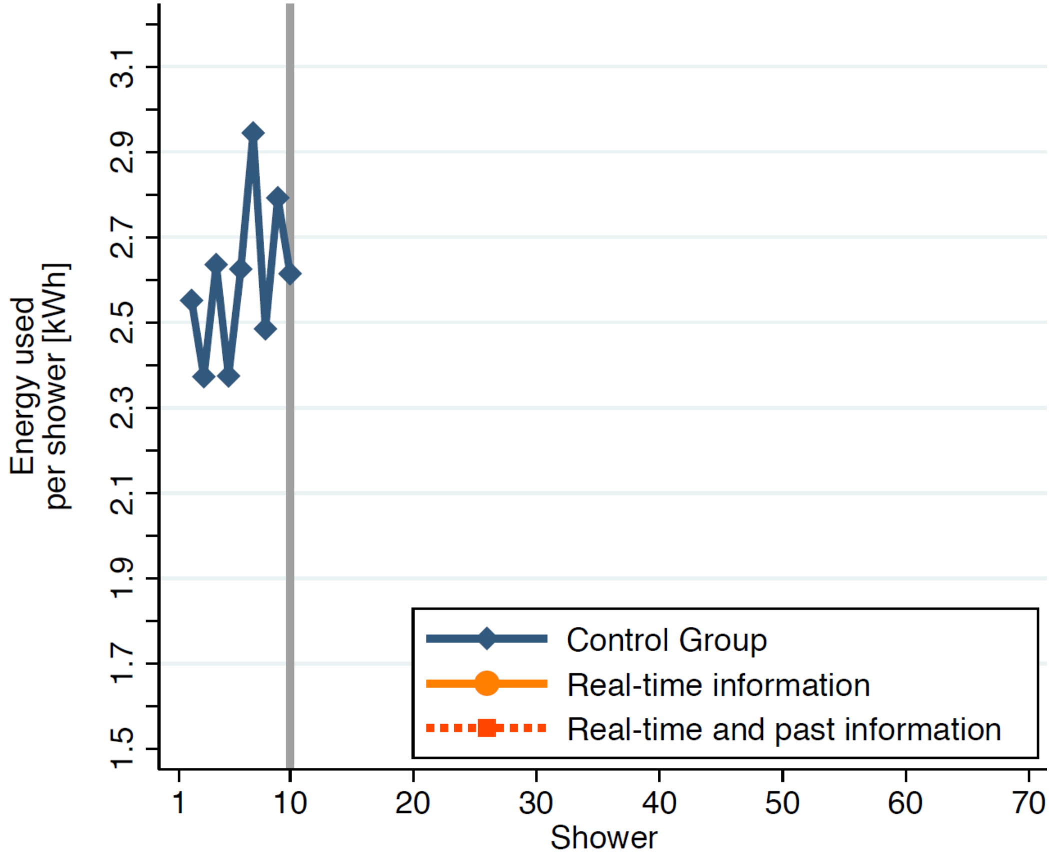
Smart shower meter
Source: Tiefenbeck et al. (2018)

Study



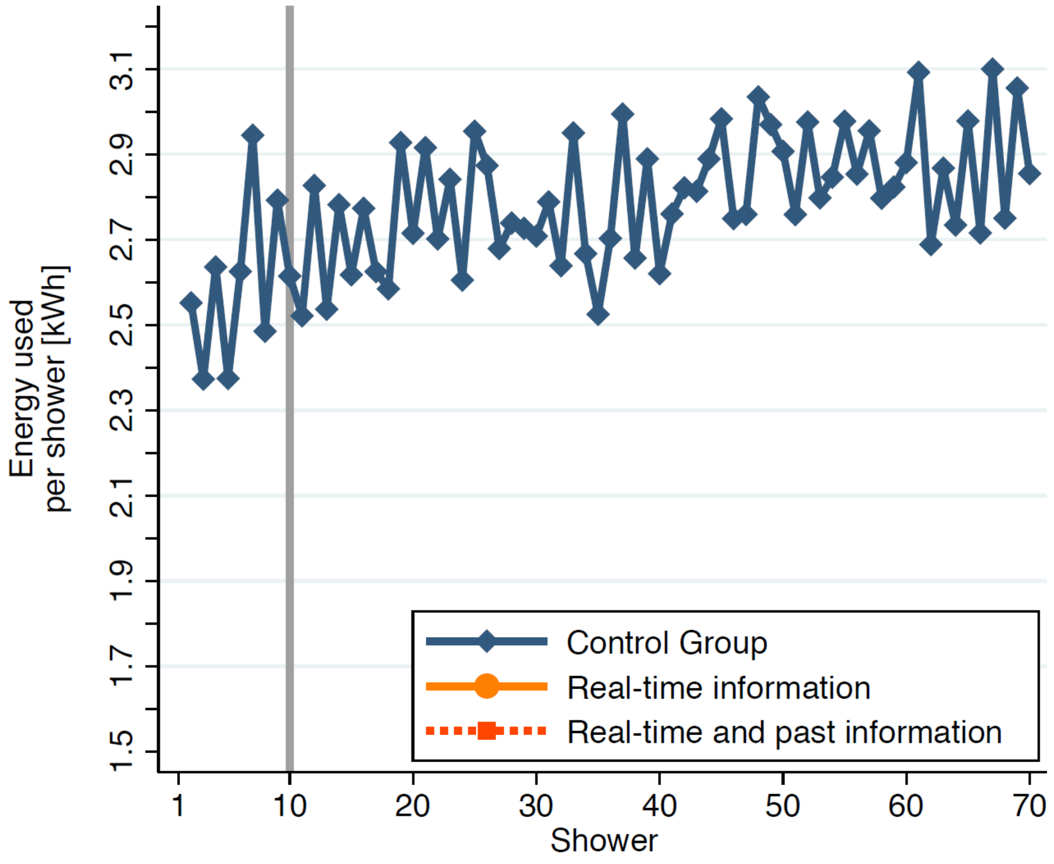
Real-time feedback Group
Real-time plus past feedback Group
Survey
No feedback:
Temperature only
Feedback
Temperature only
Survey
Baseline phase
Intervention phase
Control Group

Results: Baseline Phase



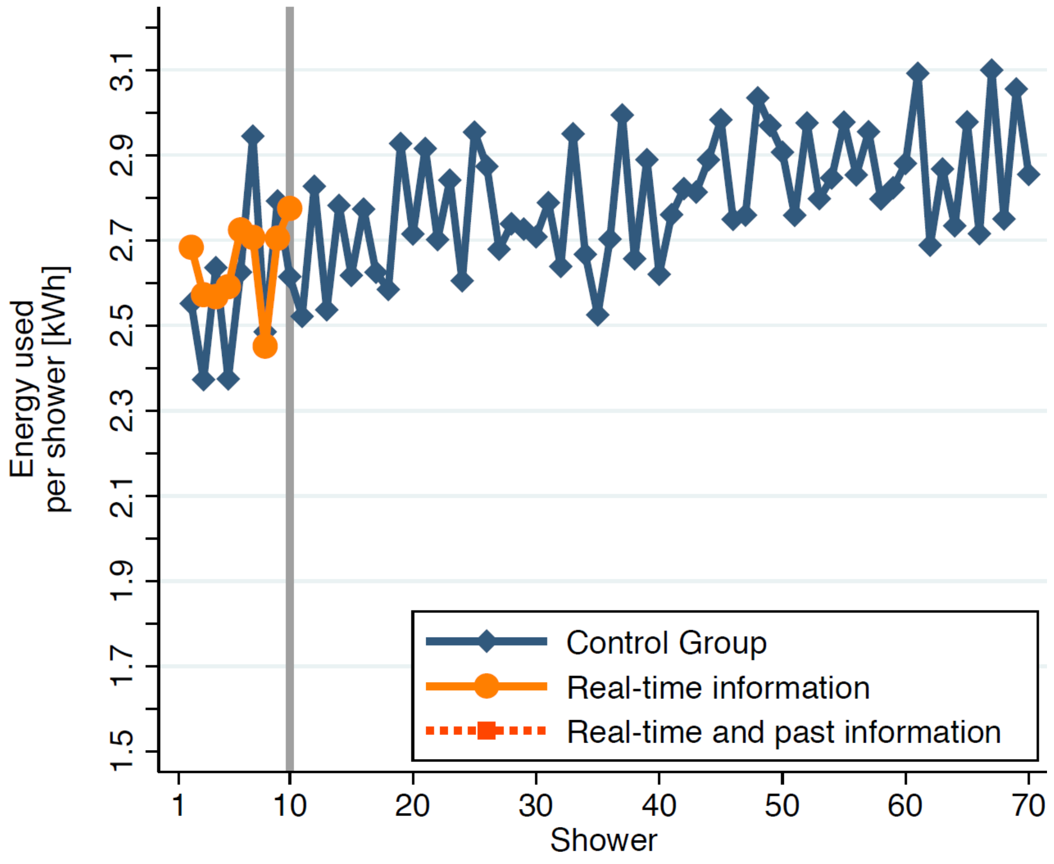
Impact of Real-Time Feedback on Energy and Water Consumption *Source: Tiefenbeck et al. (2018)*

Results: Control Group



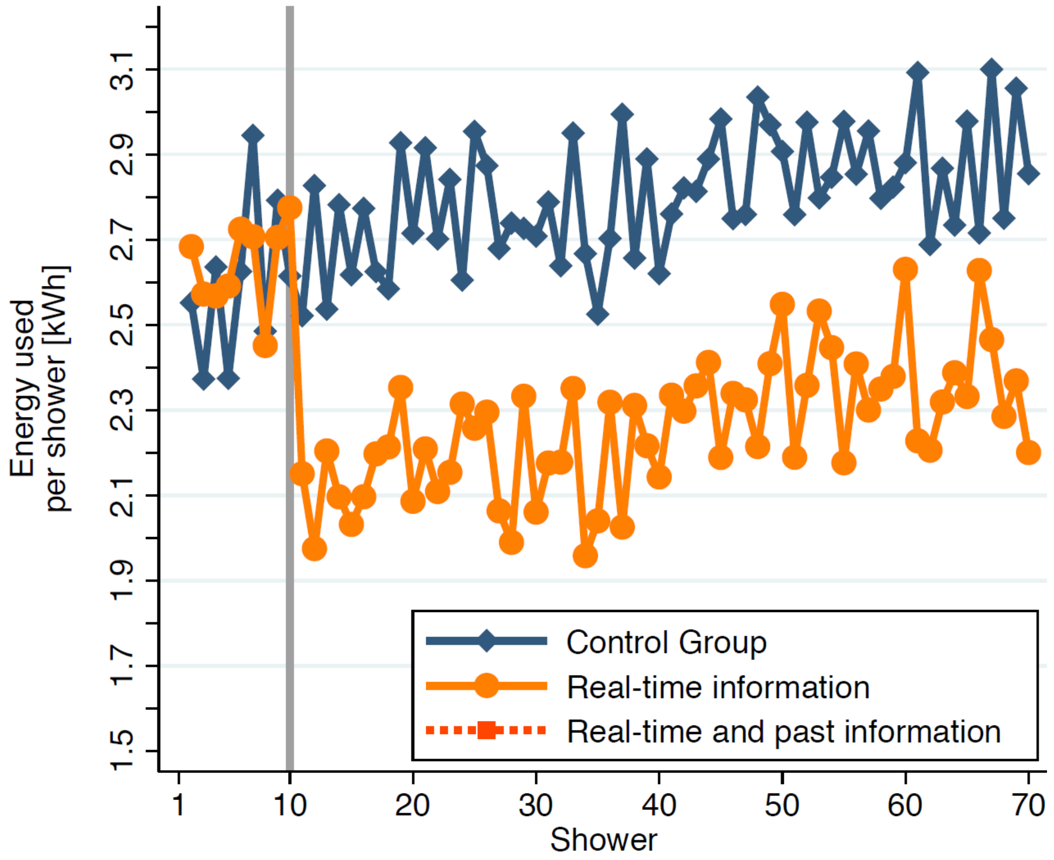
Impact of Real-Time Feedback on Energy and Water Consumption *Source: Tiefenbeck et al. (2018)*

Results: Baseline Phase



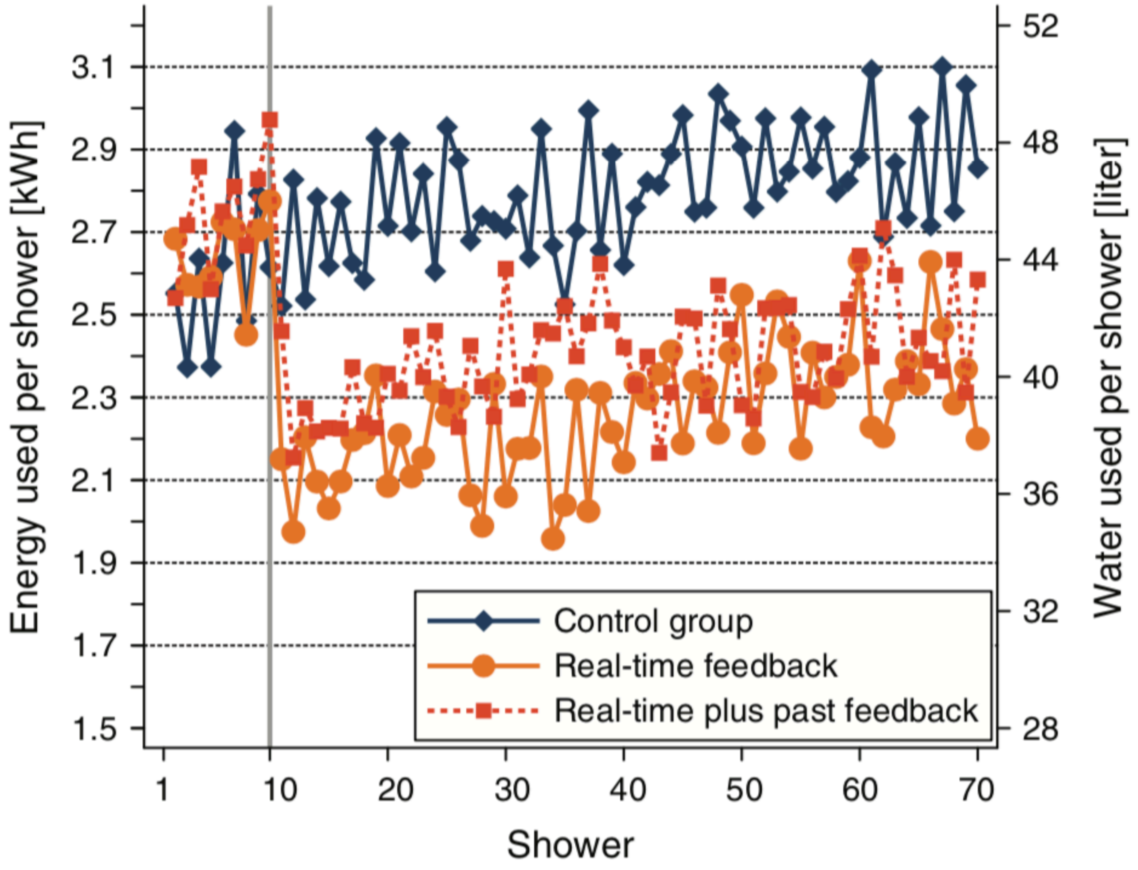
Impact of Real-Time Feedback on Energy and Water Consumption *Source: Tiefenbeck et al. (2018)*

Results: Real-time Group

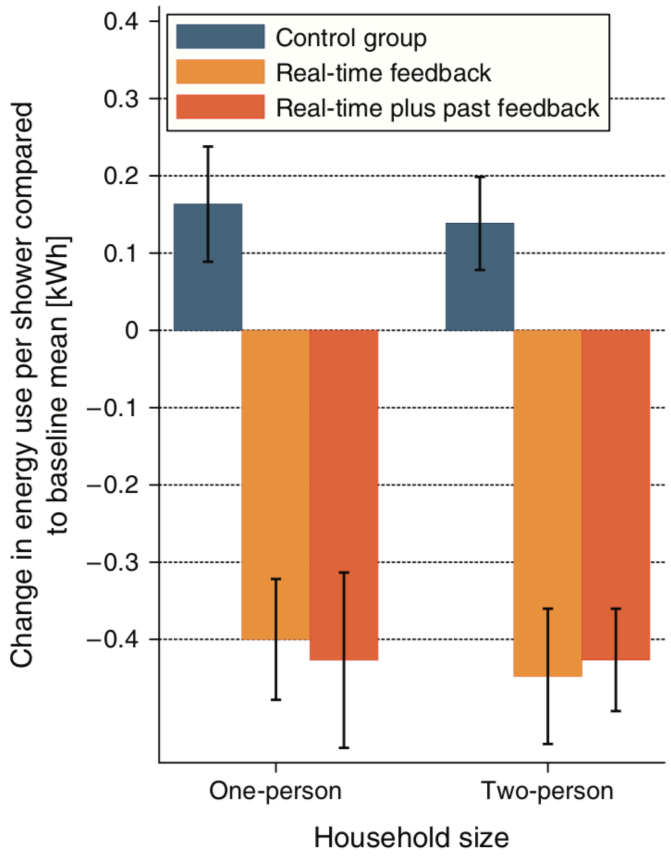


Impact of Real-Time Feedback on Energy and Water Consumption *Source: Tiefenbeck et al. (2018)*

Results: Group Comparison



Impact of Real-Time Feedback on Energy and Water Consumption *Source: Tiefenbeck et al. (2018)*



Difference Estimates for 1- and 2-Person Households *Source: Tiefenbeck et al. (2018)*

Results: Adjustments

	Shower time (sec)	Flow rate (l/min)	Avg. Temp. (°C)	Nr. of stops in water flow	Total break time (sec)
Real-time group	– 51.60	– 0.140	– 0.371	0.057	5.90
Real-time plus past feedback	– 50.18	– 0.165	– 0.260	0.081	2.67
Constant	244.38	10.998	36.204	0.530	34.23

Main treatment effects on energy use (in kWh), controlling for household and time fixed effects.
Source: Tiefenbeck et al. (2018)

Results: Subgroups

- Average household saves 0.62 kWh → -22%
- 20% with weakest intent of preserving saves 0.49 kWh
- Top quintile saves 0.74 kWh
- Nobody showered more often → no rebound!

Conclusion

- It works! Real-time feedback on a specific behavior can induce large behavioral changes
- 22% reduction in energy consumption for showering
  → 5% of the household energy use
- Savings over a year of a person showering once a day:
  215 kWh energy, 3500l water, 47kg CO_2
- No Rebound!
  - But …

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Vending Machines

- Japan: highest density of vending machines (VM) – in 2003 they acquired 0.7% of electricity consumed
- Energy costs are main component of operating cost of VMs
- Several programs to improve energy consumption
    - Local chilling and heating systems
    - Automatic light control systems
    - Low-power modes for nighttime

Principal-Agent Barriers

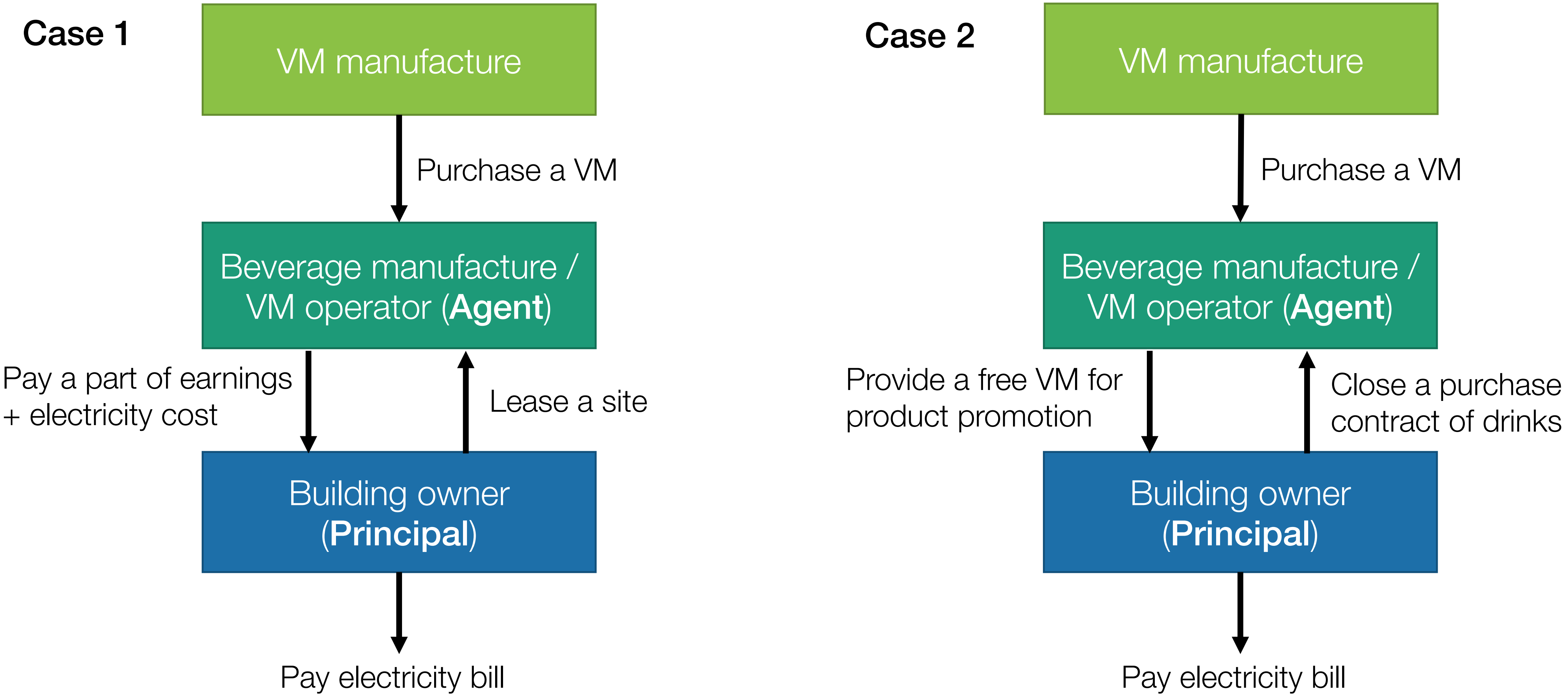
- How to quantify the energy lost due to barriers in the market?

	Can Choose Technology	Cannot Choose Technology
Direct Energy Payment	Case 1: No Problem	Case 2: Efficiency Problem
Indirect Energy Payment	Case 3: Usage and Efficiency Problem	Case 4: Usage Problem

Source: American Council for an Energy-Efficient Economy (2007)

Transactions Among Actors

VM = Vending Machine



Source: American Council for an Energy-Efficient Economy (2007)

Principal-Agent Classification of Beverage Vending Machines

	Can Choose Technology	Cannot Choose Technology
Direct Energy Payment	Case 1: No Problem → **Case 1, classical display coolers**	Case 2: Efficiency Problem → **Case 2, product-promoting display coolers**
Indirect Energy Payment	Case 3: Usage and Efficiency Problem Nr. of VM: Negligible	Case 4: Usage Problem Nr. of VM: 0%

Energy use affected by the barrier (kWh/yr) =

Nr. of running machines (units)

* per machine electricity use (kWh/yr/unit)

* fraction of the machines affected by the barrier (%)

Source: American Council for an Energy-Efficient Economy (2007)

Results: Classical Display Coolers

	Can Choose Technology	Cannot Choose Technology
Direct Energy Payment	Case 1: No Problem Nr. of VM: 2.6 mil. (100%)	Case 2: Efficiency Problem Nr. of VM: 0%
Indirect Energy Payment	Case 3: Usage and Efficiency Problem Nr. of VM: Negligible	Case 4: Usage Problem Nr. of VM: 0%

Energy use affected by the barrier (kWh/yr):

- Nr. of running machines = 2.6 million
- Per machine electricity use = 2300 kWh/yr/unit
- Fraction of the machines affected by the barrier = 0%

→ 2.6 * 2300 * 0 = **0 TWh/yr**

Source: American Council for an Energy-Efficient Economy (2007)

Results: Product-Promoting Display Coolers

	Can Choose Technology	Cannot Choose Technology
Direct Energy Payment	Case 1: No Problem Nr. of VM: 1.6 mil. (56%)	Case 2: Efficiency Problem Nr. of VM: 1.3 mil. (44%)
Indirect Energy Payment	Case 3: Usage and Efficiency Problem Nr. of VM: 0%	Case 4: Usage Problem Nr. of VM: 0%

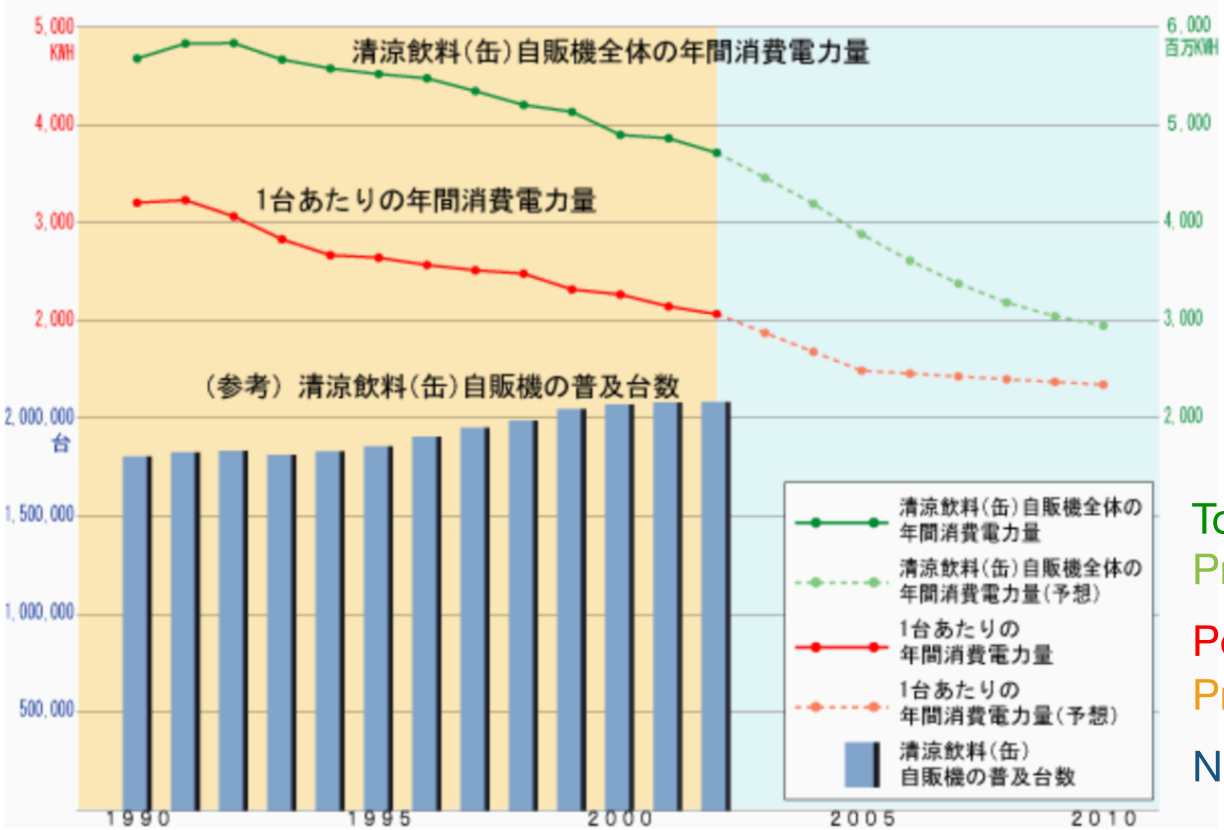
Energy use affected by the barrier (kWh/yr):

- Nr. of running machines = 2.9 million
- Per machine electricity use = 930 kWh/yr/unit
- Fraction of the machines affected by the barrier = 44%

→ 2.9 * 930 * 0.44 = **1.2 TWh/yr**

Source: American Council for an Energy-Efficient Economy (2007)

Electricity Use of Vending Machines



After efficiency improvements, the nr of VMs did not increase
→ No rebound → **Why?**

Total electricity consumption of all VMs (GWh/year)
Prediction

Per VM electricity use (kWh/year)
Prediction

Nr. of running VMs (year)

Development of Electricity Consumption of Canned Soft Drink Vending Machines from 1990 to 2010 in Japan

Source: American Council for an Energy-Efficient Economy (2007)

Conclusion

- Principal-Agent Barrier:
  - Case 1: no barrier
  - Case 2: barrier → additional energy policies needed
- With energy efficiency not more VMs → small rebound effect
  → another factor limiting the number of machines

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Overall Conclusion:
How to Minimize Rebound Effects?

- If energy costs are a minor cost component:
  improve energy efficiency – risk of rebound is small
- If energy costs are a major cost component:
  - If limiting factor is something else than energy – risk of rebound is small
  - If limiting factor is energy – risk of rebound is 100%

Thank You