The Energy Efficiency Gap: Reasons and Implications

Wed 12 & Thu 13 March, 2014
ZEW L7, 1 Mannheim, Germany
Room Luxemburg

Agenda

Start	End	Speaker	Topic
DAY 1 (Wednesday, March 12, 2014)			
4:00 PM	5:00 PM	R. Newell	Nudging energy efficiency behavior: The role of information labels
5:00 PM	5:30 PM		*Discussion*
7:00 PM	9:00 PM		*Dinner; Rheinterrassen (Rheinpromenade 15)*
DAY 2 (Thursday, March 13, 2014)			
9:00 AM	9:15 AM	A. Löschel	Energy efficiency - Recent and ongoing research at ZEW
9:15 AM	9:25 AM	R. Stavins	The energy-efficiency gap and the energy paradox
9:25 AM	9:35 AM	R. Newell	Elements of cost-minimizing energy-efficiency decisions
9:35 AM	9:45 AM		*Discussion*
The role of economic instruments			
9:45 AM	10:10 AM	L. Ryan	Economic instruments and energy efficiency policy
10:10 AM	10:35 AM	F. Wirl	Myths of conservation (programs)
10:35 AM	10:45 AM		*Discussion*
10:45 AM	11:00 AM		*Coffee break*
11:00 AM	11:25 AM	A. Lange	Learning abatement costs: On the dynamics of optimal regulation of experience goods
11:25 AM	11:40 AM		*Discussion*

Start	End	Speaker	Topic
Information problems and behavioral explanations			
11:40 AM	12:05 PM	J. Schleich	Transitions towards energy efficient lighting and rebound effects
12:05 PM	12:30 PM	E. Aydin	Energy efficiency and household behavior: The Rebound effect in the residential sector
12:30 PM	12:45 PM		*Discussion*
12:45 PM	1:30 PM		*Lunch; ZEW Bistro*
1:30 AM	1:55 AM	M. Hanemann	Buildings and energy
1:55 AM	2:20 PM	G. Giraudet	Double moral hazard and the energy efficiency gap
2:20 PM	2:45 PM		*Discussion*
Model and measurement explanations			
2:45 PM	3:10 PM	M. Tavoni	Modeling energy efficiency scenarios
3:10 PM	3:25 PM		*Discussion*
3:25 PM	3:40 PM		*Coffee break*
3:40 PM	4:05 PM	M. Filippini	Impact of energy policy instruments on the level of energy efficiency in the EU residential sector
4:05 PM	4:30 PM	R. Martin	Measurement of paradox in the EU ETS
4:30 PM	5:15 PM		*Final discussion*
5:15 PM	5:30 PM	A. Löschel; R. Newell; R. Stavins	*Wrap up and goodbye*

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List of Participants

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Nudging energy efficiency behavior:

The role of information labels

Richard Newell, Duke University
Juha Siikamäki, Resources for the Future

Workshop on The Energy Efficiency Gap: Reasons and Implications
ZEW, Mannheim, Germany, March 12, 2014

Duke UNIVERSITY ENERGY INITIATIVE

RESOURCES FOR THE FUTURE

Energy efficiency: the economic decision problem

Objective

annual operating cost

price of energy

discount rate

$$\textit{Minimize}$$
$$\textit{Total Cost} = K(E) + O(E, P_E) \times D(r, T) + \text{other costs}$$

equipment purchase cost

annual energy use

present value factor

time horizon

The "energy paradox " or "energy efficiency gap"

- Apparent reality that energy-efficient products that would pay off for adopters …are nonetheless *not* adopted
  - "Rationalizing" observed choices can require implicit discount rates much higher than market rates
  - 30+ year debate (e.g., Hausman 1979; Shama 1983; Dubin & McFadden 1984; Jaffe & Stavins 1994; Gillingham, Newell, and Palmer 2011; Alcott and Greenstone 2012)

- Explanations
  - Market failure explanations
  - Behavioral explanations
  - Model and measurement explanations

Explanations for the energy efficiency gap

- Market failure explanations
  - information problems (lack of information)
  - split incentives (e.g., renter/landlord, capital/operating budgets)
  - liquidity constraints (purchaser cannot finance more up-front cost)
  - prices don’t include externalities or are set too low through regulation
- Behavioral explanations
  - inattentiveness/salience issues
  - bounded rationality, heuristic decisionmaking
  - prospect theory (losses matter more than gains)
  - myopia (excessive weight on the near term)
- Model and measurement explanations
  - unobserved costs of adoption
  - heterogeneity: product attributes; characteristics of adopters

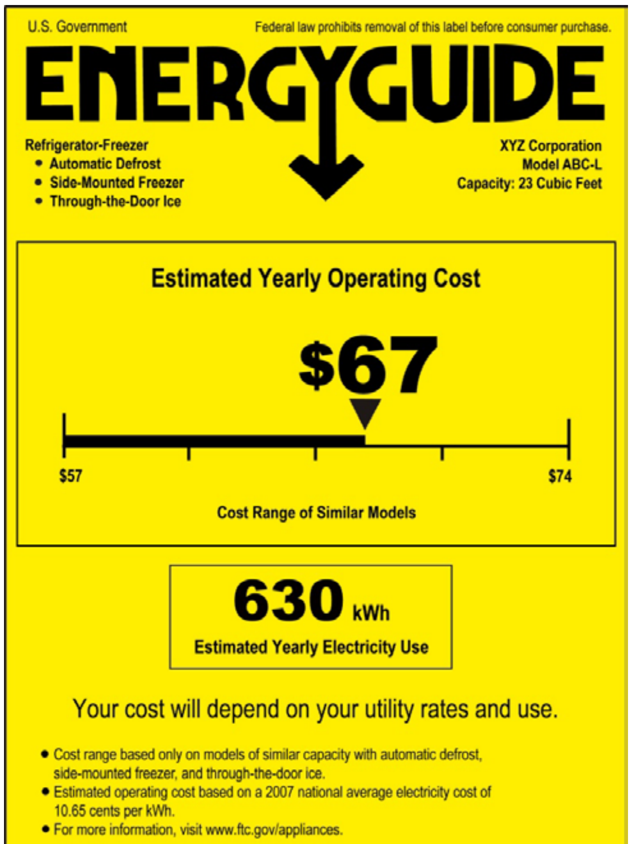
Study goals

- Evaluate alternative labeling approaches in the context of households' preferences for energy efficiency
  - systematic research lacking on whether or how existing labels affect choices
  - does information content and complexity matter?
  - what are the effects of multiple labels?

- Disentangle effects of different drivers of energy efficiency decisions
  - different drivers separately evaluated by many studies; here we seek to jointly evaluate the relative importance of different factors
  - discount rates (elicited in the survey through choice and market data)
  - individual heterogeneity (personal/household situation)
  - commonly unobserved factors, such as cost and availability of credit, likelihood of moving, income, education, and others

U.S. labeling to address information problems

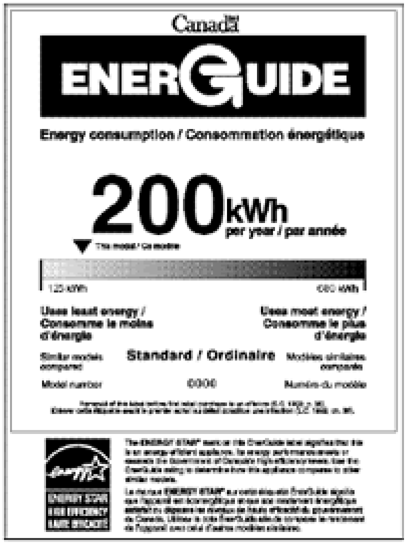
Energy Guide
(information rich)



Energy Star
("endorsement" without
detailed information

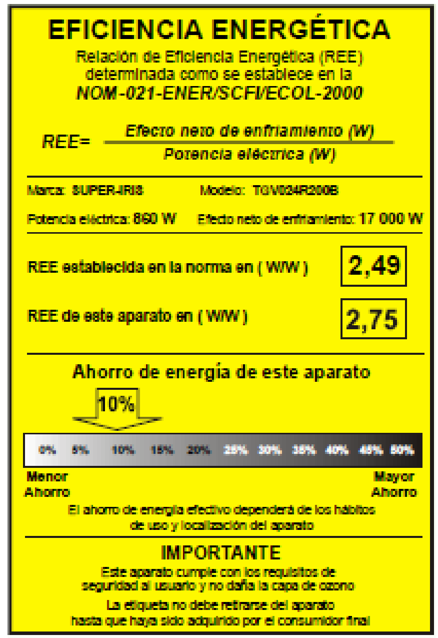
Energy labels internationally

Canada

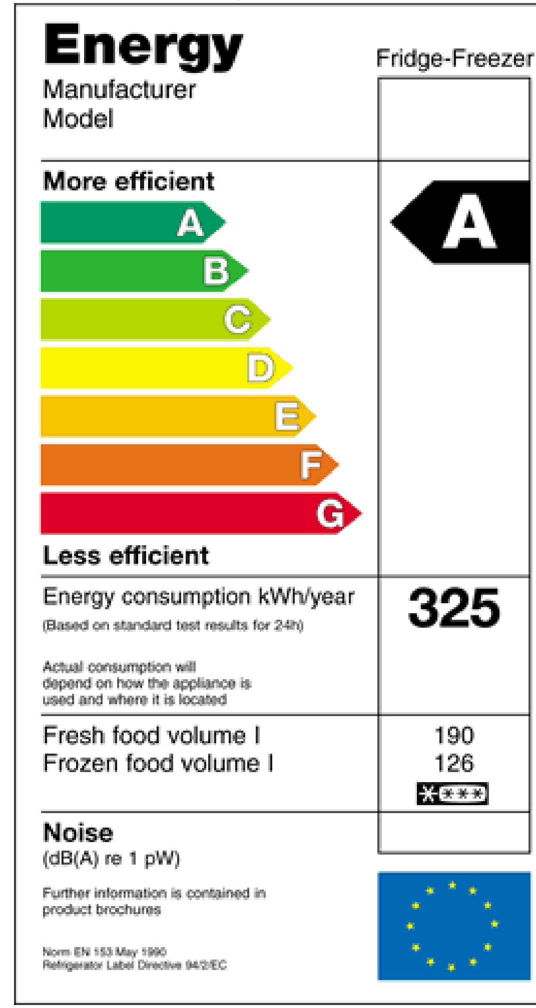


Example of an EnerGuide label for an ENERGY STAR qualified appliance.

Mexico



European Union



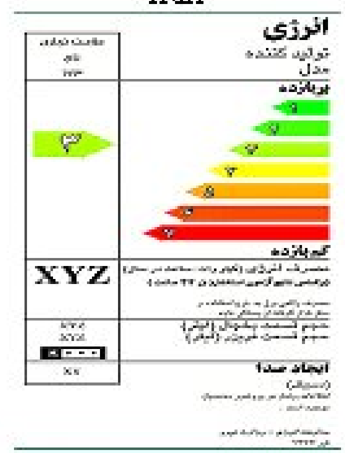
Korea

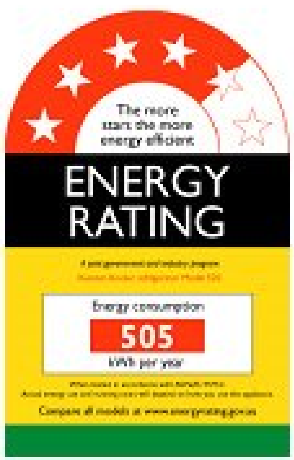
More international labels

Thailand

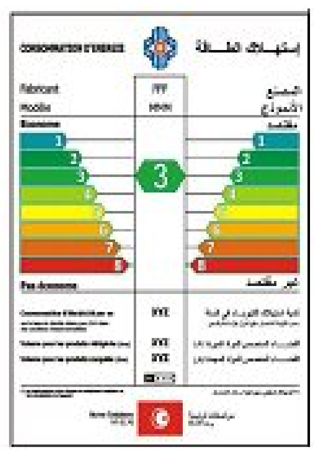
Brazil

Iran





Australia



Tunisia

China

Source: Energy Efficient Strategies (EES)

Study approach

- Household survey (responses from 1,217 single-family households)
- Evaluate immediate water heater replacement decision
- Elicit choices between different water heater alternatives
- Different alternatives randomly (but realistically) varied by price and energy use
- State-of-the art choice experiment design
  - fully computerized survey instrument which is customized as each survey respondent progresses through it
  - labeling approach randomly varied by respondent (~100 per label)
- Use elicited data to estimate households' valuation of energy efficiency under different labeling treatments
- Elicit data on discount rates, credit situation, likelihood of moving, etc.

Labeling alternatives evaluated (12 treatments)

Variations on Energy Guide label

1. Current label: Energy Guide w/ Annual Operating Cost, Range, & Energy Use (kWh, therms)
2. Energy Guide, w/ only Annual Operating Cost & Range
3. Energy Guide, w/ only Annual Energy Use (kWh, therms)
4. Annual Operating Cost & Range
5. Annual Operating Cost

Energy Star logo

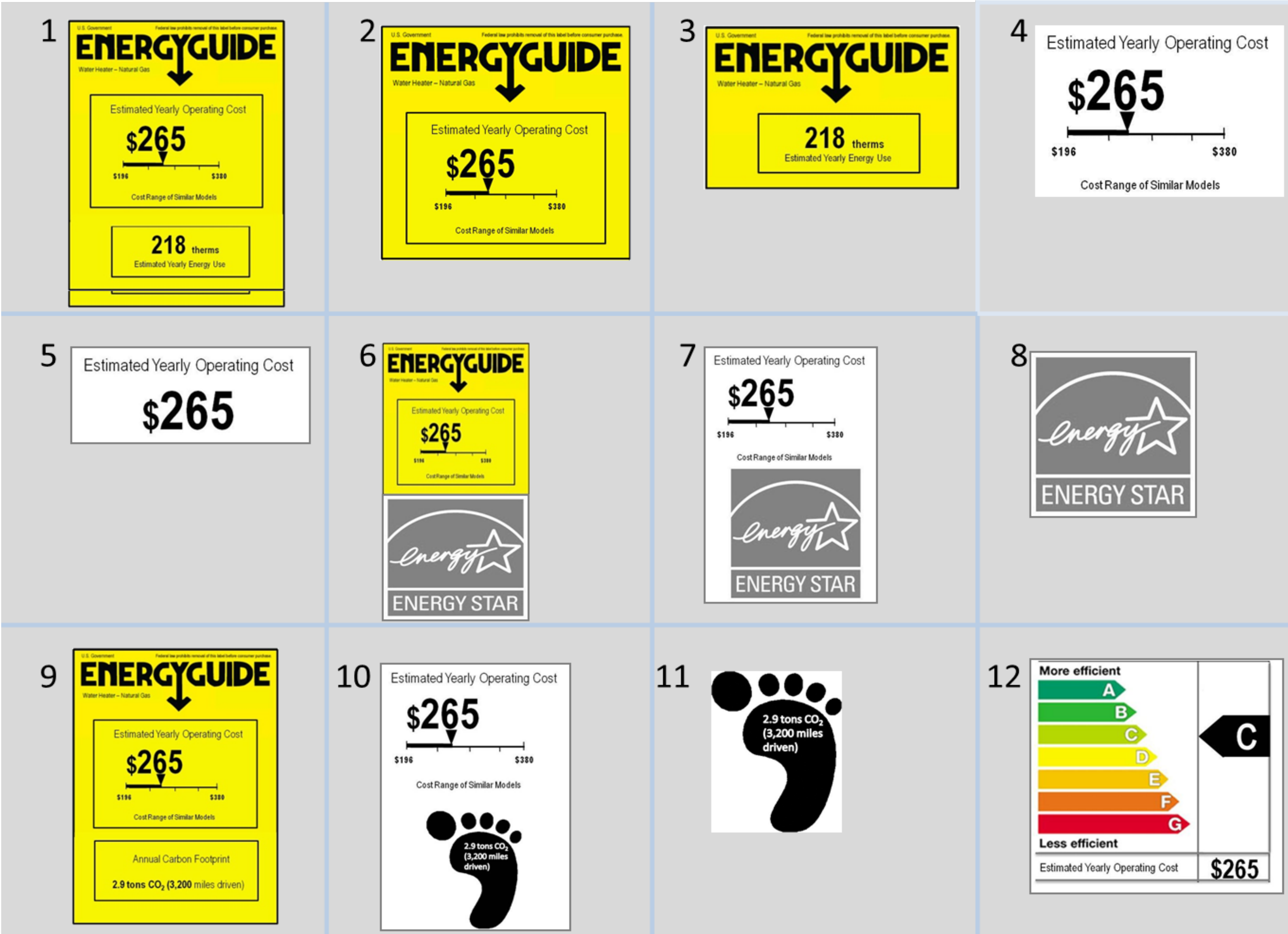
6. Energy Star + Energy Guide w/ Annual Operating Cost & Range
7. Energy Star + Annual Operating Cost & Range
8. Energy Star Only

CO_2 information

9. CO_2 Emissions + Energy Guide w/ Annual Operating Cost & Range
10. CO_2 Emissions + Annual Operating Cost & Range
11. CO_2 Emissions Only

Efficiency grade

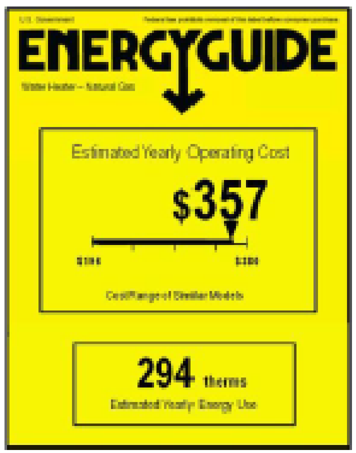
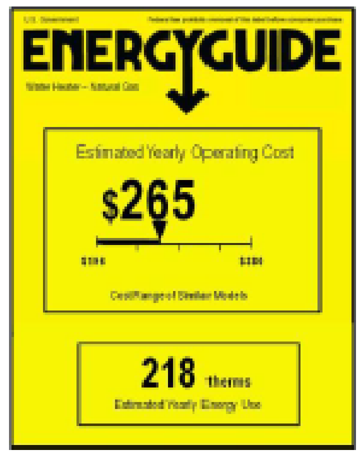
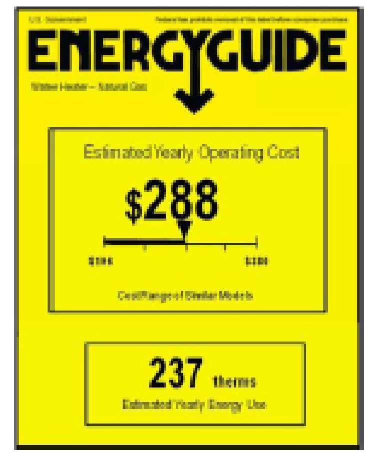
12. EU-style Efficiency Grade + Annual Operating Cost


1
ENERGYGUIDE
Estimated Yearly Operating Cost
$265
Cost Range of Similar Models
218 therms
Estimated Yearly Energy Use
2
ENERGYGUIDE
Water Heater – Natural Gas
Estimated Yearly Operating Cost
$265
$196
$380
Cost Range of Similar Models
3
ENERGYGUIDE
Water Heater – Natural Gas
218 therms
Estimated Yearly Energy Use
4
Estimated Yearly Operating Cost
$265
$196
$380
Cost Range of Similar Models
5
Estimated Yearly Operating Cost
$265
6
ENERGYGUIDE
Estimated Yearly Operating Cost
$265
energy
ENERGY STAR
7
Estimated Yearly Operating Cost
$265
$196
$380
Cost Range of Similar Models
energy
ENERGY STAR
8
energy
ENERGY STAR
9
ENERGYGUIDE
Estimated Yearly Operating Cost
$265
Cost Range of Similar Models
Annual Carbon Footprint
2.9 tons CO2 (3,200 miles driven)
10
Estimated Yearly Operating Cost
$265
$196
$380
Cost Range of Similar Models
2.9 tons CO2 (3,200 miles driven)
11
2.9 tons CO2 (3,200 miles driven)
12
More efficient
A
B
C
D
E
F
G
Less efficient
C
Estimated Yearly Operating Cost
$265

Choice Question Example 1

Consider choosing between the following three water heater options. Please think that these are the only options available to you and you have to make the purchase.

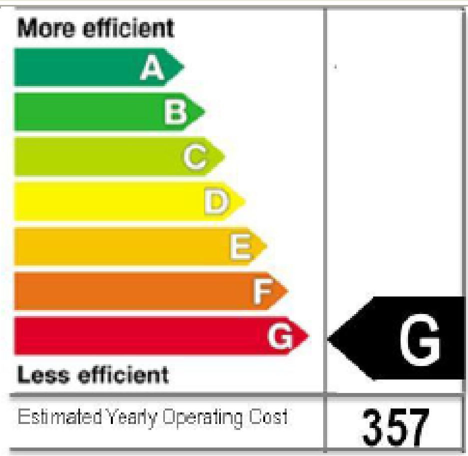
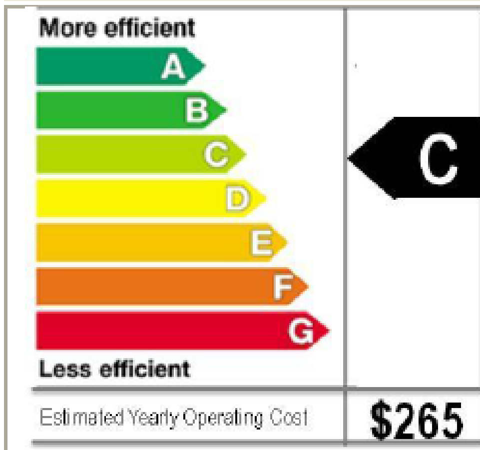
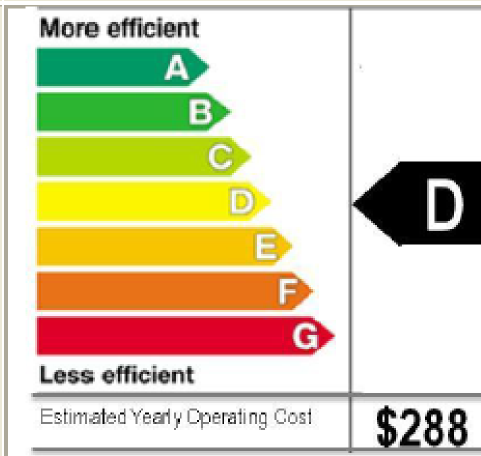
Water Heater Decision 1

	Water Heater A	Water Heater B	Water Heater C
Purchase price	$400	$650	$550
Energy Use			
Your choice from these options?	☐ A	☐ B	☐ C

Choice Question Example 2

Consider choosing between the following three water heater options. Please think that these are the only options available to you and you have to make the purchase.

Water Heater Decision 1

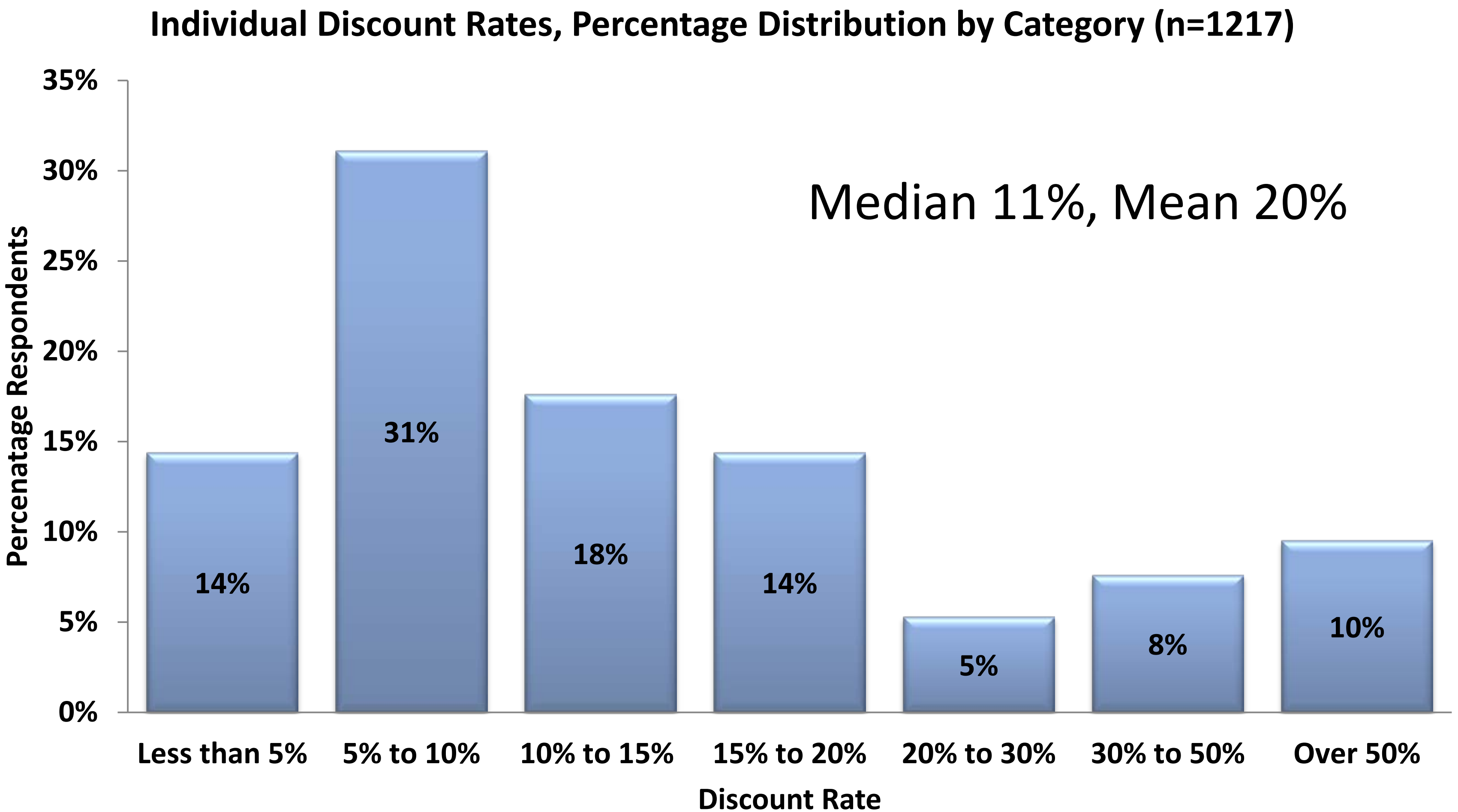
	Water Heater A	Water Heater B	Water Heater C
Purchase price	**$400**	**$650**	**$550**
Energy Use			

Your choice from these options?	☐ A	☐ B	☐ C

Eliciting individual-specific discount rates

- Cash-over-time choice approach similar to prior work
  - e.g., "Eliciting Individual Discount Rates," M Coller, M Williams, *Experimental Economics, 1999)*
- Elicit choices between two cash payment alternatives
  - Payment A is delivered in one month
  - Payment B is delivered in 12 months
  - Both tax free, certain, the only difference is the delivery date and payment amount
- Payment A always equals $1000; Payment B is greater
- Sequence of questions that vary Payment B
  - Payment B has increasing values ($1019-$2500) equal to $1000 present value at discount rates of 2% up to 100%
  - Stop when the respondent switches to the 12-month option
- Individual discount rate implicit in the choices

What individual discount rates are revealed by the cash-over-time choice task?



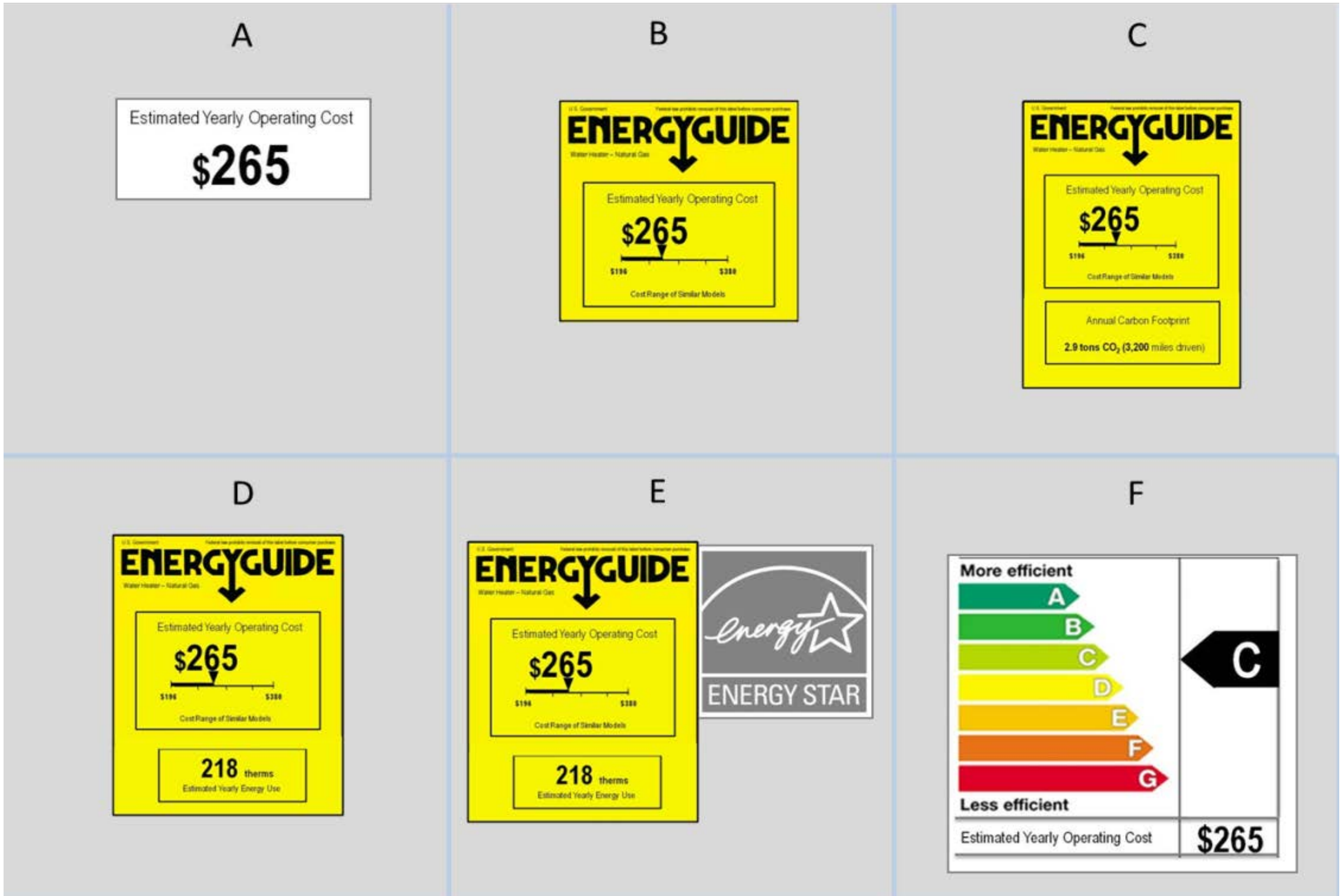
Estimating impact of information on WTP for EE

- Predict the probability of elicited choices as a function $U = f(\cdot)$ of the attributes of each alternative
  - discrete choice, random utility model, maximum likelihood
  - normalize coefficients to allow WTP interpretation
- $U = \lambda\ [\ Price + \gamma_j\ Discounted\ Energy\ Cost + \eta_j X\ ]$
  - λ estimates the effect of purchase price
  - γ_j estimates \$ WTP per \$ saved in discounted energy operating costs, conditional on information treatment j
    - cost-minimizing behavior would imply $\gamma_j = 1$
  - η_j estimates \$ WTP associated with other attributes
- Discounted energy costs computed in two ways
  (1) individually-elicited rates; (2) uniform 5% rate

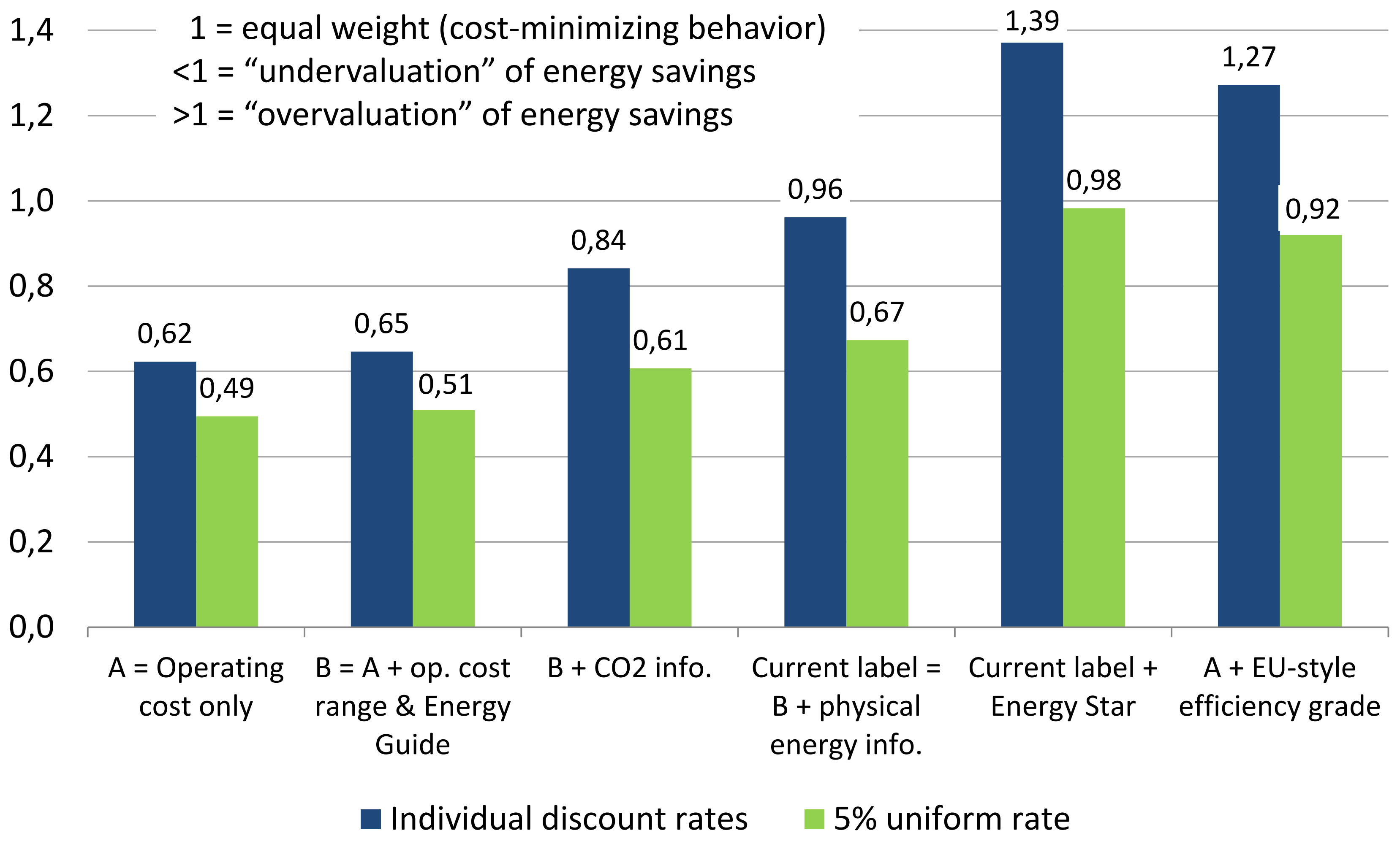
Structuring estimation and interpretation by representing labels as information composites

- Rather than estimate the impact of 12 different treatments, we express labels in terms of their key information elements
  - more intuitive and allows more structurally-sensible specification
- Information elements (interacted with discounted energy cost)
  1. Any operating cost information included (yes/no)
  2. Continuous operating cost information included (yes/no)
  3. Energy Guide image included (yes/no)
  4. Energy Star logo included (yes/no)
  5. Physical energy info. (therms, kWh) included (yes/no)
  6. CO_2 emissions information included (yes/no)
  7. Relative energy efficiency grade information included (EU-style label) (yes/no)
- Also include separate terms for energy use, CO_2, Energy Star

Six composite treatments that capture key information attributes (money, physical energy, CO_2, endorsement)



Results: $ WTP per $ saved in discounted energy operating costs



Other WTP results based on exposure solely to physical information

Variable	Estimate		Comparison
	Individual discount rates	5% discount rate	
CO_2 reductions ($/ton)	19.6	13.2	$20-30/ton central estimates for social cost of carbon
Electricity savings (¢/kWh)	8.9	6.4	11.5 ¢/kWh residential avg. retail price in 2010
Natural gas savings ($/therm)	1.04	0.75	$1.14/therm residential avg. retail price in 2010

Concluding thoughts

- Willingness to pay for energy efficiency is significantly affected by
  - information content of labels
  - discount rate assumptions (individual vs. uniform 5%)
- Monetary operating cost information is most important
  - information on physical energy and CO_2 emissions have additional, but lesser impact on choices
- Whether you "accept" individual discount rates has a significant implication for the degree of labeling "nudge" and/or support for other efficiency policies
  - using *individual discount rates*, current Energy Guide label yields roughly cost-efficient WTP for energy efficiency
  - using a *lower 5% discount rate*, the more suggestive Energy Star logo or EU-style efficiency grade appear to induce more cost-efficient behavior

Extras

Statistically modeling discrete choice data

- Pr_{ij}=Pr(person i chooses alt j) =f(U_{ij}, X_{ij}, e_{ij})
  - U denotes utility, X denotes the attributes of alternative j, e is an unobserved iid random variable
- Random Utility Model (fixed effects logit)
  - $U_{ij} = V_{ij} + e_{ij}$
  - *Indirect utility* $V_{ij} = \sum_{i=k}^{K} \beta_{ik} X_{ikj}$
  - e_{ij} *~ extreme value type I*
  - X_{ij} *denotes the attributes of alternatives in the choice set*
- Then the probability of person *i* choosing alternative *j* is $P_{ij} = \frac{e^{V_{ij}}}{\sum_{j=1}^{J} e^{V_{ij}}}$
- Find parameters *ß* which maximize the likelihood of observing the elicited choices, given P_{ij} and X_{ij}

Study approach

- Basic setting
  - Household survey (responses from 1,217 households)
  - Fully computerized survey instrument which is customized as each survey respondent progresses through it
  - Evaluate sudden water heater replacement decisions
  - Elicit choices between different water heater alternatives
  - Different alternatives randomly but realistically varied by price and energy use
  - Labeling approach randomly varied by respondent
  - Use elicited data to estimate households' valuation of energy efficiency under different labeling treatments
  - Elicit data on discount rates, credit situation, likelihood of moving, and so forth; use those data to examine the relative importance of different drivers of preferences for energy efficiency

- Strengths of using a survey based approached
  - Enables randomized experiments
  - Enables using a controlled, simplified, and uniform setting across different households
  - Focuses on the essential features of information disclosure
  - Enables examining labeling alternatives currently not in the market

- Possible limitations
  - Though realistic, the setting somewhat different from actual choices (for example, the label and energy information prominently displayed)
  - Hypothetical choices may differ from actual behavior, though the survey includes recommended reminders to choose as in reality
  - Data probably most robust for estimating relative treatment effects; especially the estimates of households' absolute valuation of energy efficiency must be interpreted given the overall approach

Why Water Heater?

- Practically every house has one
- Sudden replacement (imposed in the survey) is conceivable
- Investment and annual energy cost both are considerable
- Relatively uniform in functionality, installation, usage, available models, quality
  - Helps abstract away "irrelevant" attributes
  - Brand considerations not central
- Also considered window AC units and clothes washers/dryers
  - Difficult to formulate a uniform yet realistic model across all households
  - Sudden replacement less realistic
  - Usage and models vary considerably
  - Occurrence of especially window AC relatively rare

Credit Choice Problem

Credit A		Credit B	Discount Rate for NPV of Credit A and B Are Equal
$1,000	vs.	$1,019	2.1%
$1,000	vs.	$1,037	4.0%
$1,000	vs.	$1,057	6.0%
$1,000	vs.	$1,076	8.0%
$1,000	vs.	$1,096	10.0%
$1,000	vs.	$1,116	12.0%
$1,000	vs.	$1,137	14.0%
$1,000	vs.	$1,158	16.0%
$1,000	vs.	$1,179	18.0%
$1,000	vs.	$1,201	20.0%
$1,000	vs.	$1,258	25.0%
$1,000	vs.	$1,317	30.0%
$1,000	vs.	$1,443	40.0%
$1,000	vs.	$1,581	50.0%
$1,000	vs.	$1,733	60.0%
$1,000	vs.	$1,989	75.0%
$1,000	vs.	$2,501	100.0%

Choice experiment design features

- Only labeling treatment varies across respondents; the instrument is otherwise exactly the same
- Different labels designed with maximal consistency (image and font size, font type, type of information presented, so forth)
- Purchase price and annual operating costs range similarly to models currently in the market
- Water heater fuel (natural gas, electricity, propane, oil) determines annual operating cost (customized mid-survey using data on respondent's home)
- Estimated CO2 emissions (treatments 3, 8, 10) also correspond to actual estimated emissions
  - Expressed in pounds and miles driven equivalent (avg. US passenger vehicle, 21 mpg, 19.4 lbs CO_2 / gallon)
  - Emissions vary by water heater fuel (electric 0.524 lbs per kWh, natural gas 13.446 lbs per therm)

- Statistical experimental design purposed to help precisely identify potential treatment effects
  - Vast number of possible overall designs exists (many attributes, many levels, 6 choices by each respondent, 3 alternatives by choice)
  - Chosen design maximizes statistical efficiency (min standard errors, D-efficiency, Bayesian approach)
  - Strictly dominated alternatives eliminated from each choice set
  - In the end, one hundred possible 6 choice question attribute and choice alternative designs, 12 labeling treatments, two fuel options
  - Individualized survey instrument populated mid-survey
  - Exactly similar attribute level designs across treatments – avoids random confounding in the estimation of treatment effects

Sample

- Knowledge Networks computerized survey panel
- Owners of single-family homes (detached, attached)
- Heads of household selected as respondents
- About 100 households in each treatment (1217 total)
- Randomized treatments enable clean identification of treatment effects

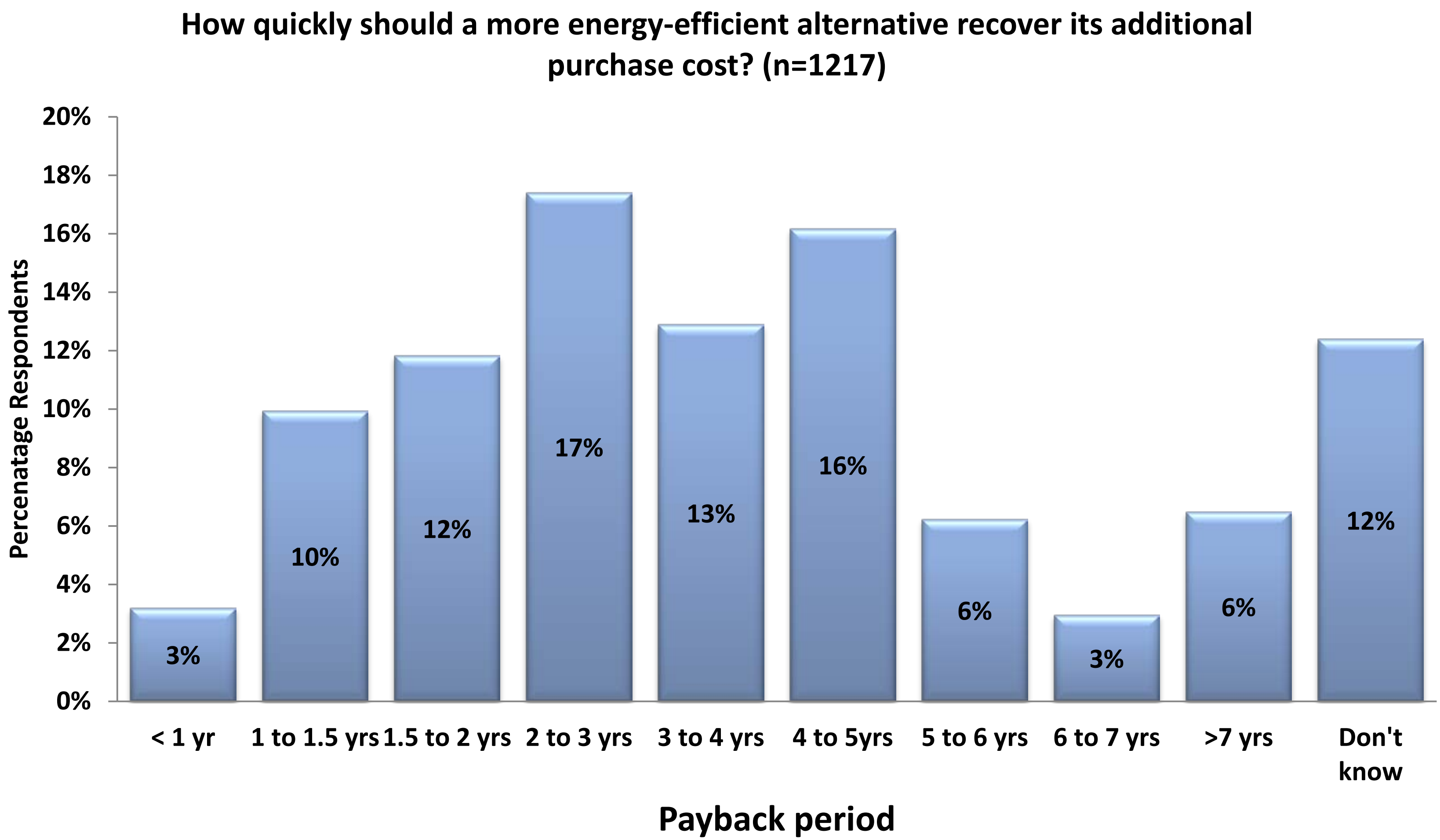
Survey Outline

1) Introduction
2) Describe your current water heater (fuel, capacity, age)
3) Considering having to suddenly replace the water heater, how importance are different considerations to your new water heater choice?
4) Choice questions (introduction + 6 choices, each with three alternatives)
5) Questions on payback time, WTP for energy savings
6) Series of questions eliciting individual discount rates
7) Questions on current credit situation, loans, loan rates

Attribute Levels

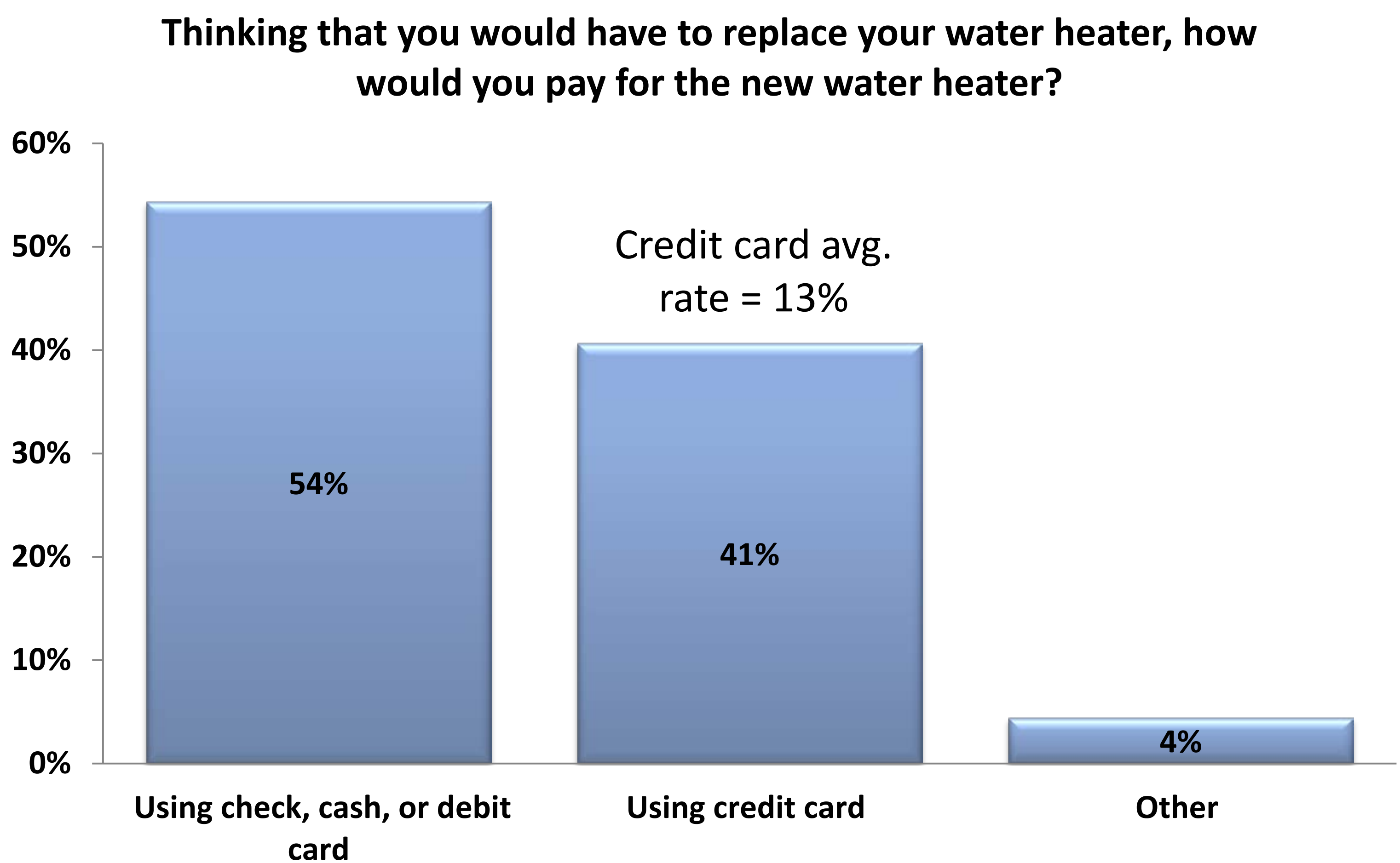
Attribute	# of Levels	Min	Max	Notes
Price	7	\$420	\$1,440	Represents 10 to 90 percent range of the MSRP of actual models in the market
Energy Use - Natural Gas	7	\$219	\$357	Represents 10 to 90 percent range of the estimated energy use of actual models in the market
Energy Use - Other Fuels	7	\$368	\$602	Represents 10 to 90 percent range of the estimated energy use of actual models in the market
Energy Star	2	No Label	Energy Star Label	Four lowest levels of energy use qualify for Energy Star
CO_2 Emissions – Natural Gas	7	2.4 tons (2,600 miles)	3.9 tons (4,300 miles)	Estimated CO_2 emissions corresponding to each seven levels of energy use. "Miles driven" denotes the number of miles driven on an average US passenger car which generated the same CO_2 emissions. CO2 emissions are not randomized but match energy use.
CO2 Emissions – Other Fuels	7	4.1 tons (4,400 miles)	6.6 tons (7,200 miles)	

What *payback period* do these consumers use?



Mean = 3.5 years (assuming 10 years for the category >7 years)

What is the relevant *market interest rate* for each purchaser?



Credit card avg. rate = 13%

Mortgage avg. rate = 5%

Energy Efficiency

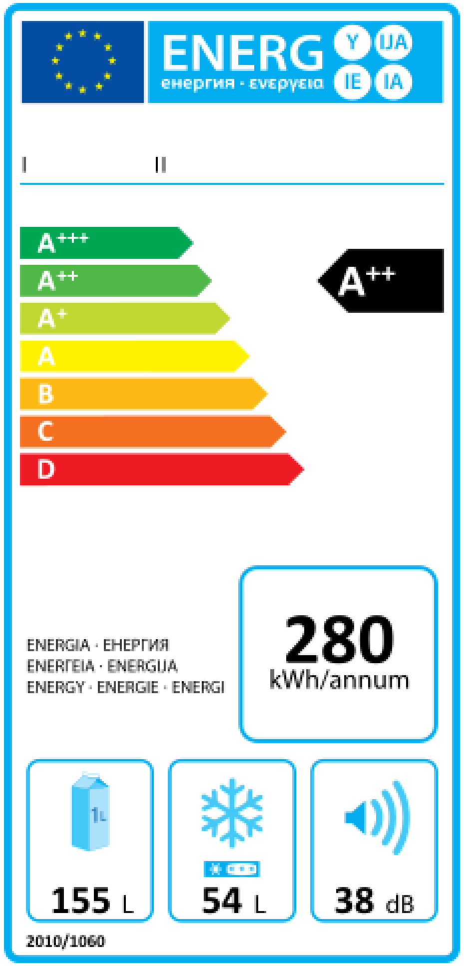
Recent and Ongoing Research at ZEW

Andreas Löschel

The Energy Efficiency Gap: Reasons and Implications

Mannheim, March 12-13, 2014

Energy efficiency high on the policy agenda



EU's 20-20-20 targets

- 20% increase in energy efficiency by 2020
- Emission standards for cars: 95 g CO2 / km by 2020

The German *Energiewende*

- Primary energy consumption shall be halved by 2050
- Demand for heating in buildings shall fall even by 80%
- Energy productivity shall increase by 2.1% annually

"Social, ecological and economic dimensions of sustainable energy consumption in residential buildings" (SECO@home)

- 03/2008 – 11/2010
- Survey of over 1,200 households
- Discrete choice experiment

SECO@home

Why do German house owners (not) undertake energy retrofits?

- Economic and technical factors matter most
- Professional energy advice helps to stimulate energy retrofit activities

What role do environmental benefits play in that decision?

- Influence heating choices positively; but no effect on insulation choices rebound

“The social dimension of the rebound effect” (REBOUND)

- 09/2010 – 11/2013
- Survey of over 6,000 households
- Econometric and CGE analyses

Main contributions:

- Empirical evidence that more efficient (and renewable) heating systems run significantly longer during the cold season (effect is larger for low-incomes)
- Quantifying the overall rebound in the individual transport sector: 56%
- Decomposing the rebound into direct and indirect effects
- Extending the rebound concept to multi-regional perspective (international spillover effects reduce rebound)

SOKO Energiewende

"Sociopolitical Impact of the German Energy Transition"

- 08/2013 – 07/2016
- Survey of about 3,000 households (planned)
- Household Budget Survey from Destatis
- Economic lab experiments

Key research questions:

- Are private households increasingly affected by rising energy costs in the course of the German energy transition?
- What are distributional effects of the policy?
- How can fuel poverty be avoided?

→ Better understanding of interactions in energy policy and social policy

"Future Infrastructures for Meeting Energy Demands"

- 09/2011 – 08/2016
- Interdisciplinary research

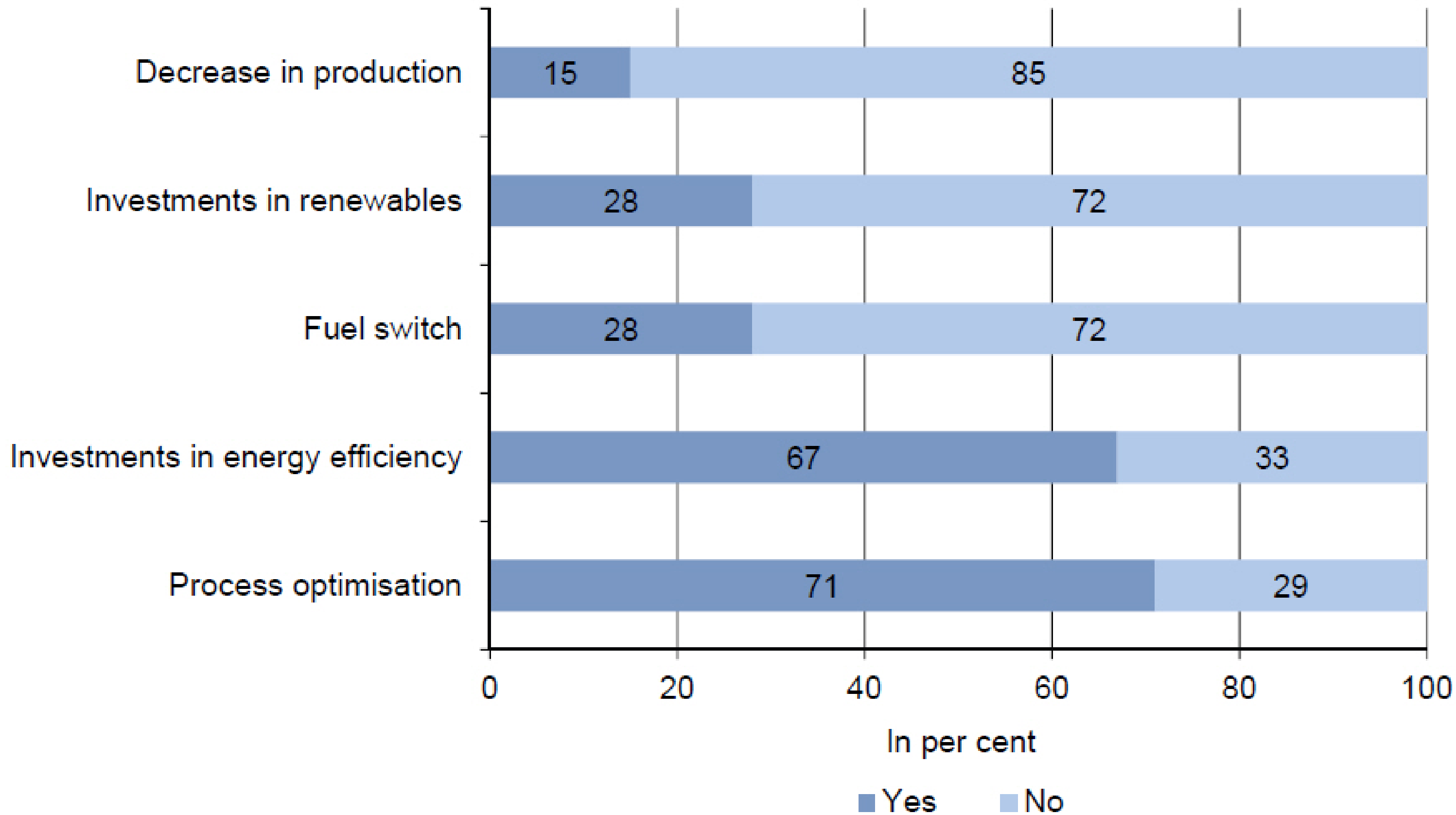
Complex relationships between energy supply, energy demand, and contextual conditions:

- Energy infrastructure and technical change
- Determinants of household decisions and behavior
- Determinants of industrial decisions and behavior
- ...

„KfW / ZEW CO_2-Barometer“

Annual survey of German companies regulated under the EU ETS

BAROMETER



CO2 abatement measures implemented since 2008

The Energy-Efficiency Gap and The Energy Paradox

Robert N. Stavins

Albert Pratt Professor of Business and Government
John F. Kennedy School of Government, Harvard University
Director, Harvard Environmental Economics Program

The Energy Efficiency Gap: Reasons and Implications

Center for European Economic Research (ZEW)
Harvard Environmental Economics Program
Duke Energy Initiative
Mannheim Germany, 12-13, March 2014

What is the “energy-efficiency gap (or “energy paradox”)?

- **Basic definition:** the *apparent* reality that some energy-efficiency technologies that would pay off for adopters … are nevertheless *not* adopted → *the energy paradox*

- **Broader definition:** the apparent reality that some energy-efficiency technologies that would be *socially efficient* are not adopted → *the energy-efficiency gap*

- ***Our Focus: Why*** are such technologies **not adopted**? Answers to that question have potentially important policy implications.

Potential Explanations of the Paradox/Gap

- ***Market-Failure*** Explanations
  - Information problems (principal-agent issues, asymmetric information)
  - Energy market failures (externalities, average-cost electricity pricing)
  - Capital market failures (liquidity constraints, particularly in LDCs)
  - Innovation market failures (R&D spillovers)

- ***Behavioral*** Explanations
  - Inattentiveness/salience issues
  - Myopia/short sightedness
  - Prospect theory/reference point issues
  - Bounded rationality & heuristic decision-making
  - Systematically biased beliefs

- ***Model and Measurement*** Explanations
  - Understated costs of adoption & ignored product characteristics
  - Overstated benefits of adoption
  - Incorrect discount rate
  - Uncertainty, irreversibility, & option value
  - Heterogeneity in benefits & costs across potential adopters

Elements of cost-minimizing energy-efficiency decisions

Richard Newell, Director, Duke University Energy Initiative
Gendell Professor of Energy and Environmental Economics

Workshop on the Energy Efficiency Gap: Reasons and Implications
March 13, 2014 | Mannheim, Germany

Duke University | ENERGY INITIATIVE

Elements of cost-minimizing energy-efficiency decisions

Objective

discounted operating costs

$$Minimize \; Total\ Cost = K(E) + O(E, P_E) \times D(r, T) + \text{other costs}$$

equipment purchase cost

assessment time, negative attributes, etc.

Elements of cost-minimizing energy-efficiency decisions

Objective

$$Minimize$$
$$Total\ Cost = K(E) + O(E, P_E) \times D(r, T) + \text{other costs}$$

equipment purchase cost

annual energy use

Elements of cost-minimizing energy-efficiency decisions

Objective

annual operating cost

price of energy

$$Minimize\ Total\ Cost = K(E) + O(E, P_E) \times D(r, T) + \text{other costs}$$

equipment purchase cost

annual energy use

Elements of cost-minimizing energy-efficiency decisions

Objective

annual operating cost

price of energy

discount rate

$$Minimize$$

$$Total\ Cost = K(E) + O(E, P_E) \times D(r, T) + \text{other costs}$$

equipment purchase cost

annual energy use

present value factor

time horizon

Elements of cost-minimizing energy-efficiency decisions

Objective

annual operating cost

price of energy

discount rate

$$Minimize\ Total\ Cost = K(E) + O(E, P_E) \times D(r, T) + \text{other costs}$$

equipment purchase cost

annual energy use

present value factor

time horizon

1. Are product offerings and pricing economically efficient?

Elements of cost-minimizing energy-efficiency decisions

Objective

annual operating cost

price of energy

discount rate

$$Minimize\ Total\ Cost = K(E) + O(E, P_E) \times D(r, T) + \text{other costs}$$

equipment purchase cost

annual energy use

present value factor

time horizon

2. Are energy operating costs inefficiently priced and/or understood?

Elements of cost-minimizing energy-efficiency decisions

Objective

annual operating cost

price of energy

discount rate

$$Minimize$$
$$Total\ Cost = K(E) + O(E, P_E) \times D(r, T) + \text{other costs}$$

equipment purchase cost

annual energy use

present value factor

time horizon

3. Are product choices cost-minimizing in present value terms?

Elements of cost-minimizing energy-efficiency decisions

Objective

annual operating cost

price of energy

discount rate

$$Minimize$$
$$Total\ Cost = K(E) + O(E, P_E) \times D(r, T) + \text{other costs}$$

equipment purchase cost

annual energy use

present value factor

time horizon

4. Do other costs inhibit more energy-efficient decisions?

For more information

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ECONOMIC INSTRUMENTS AND ENERGY EFFICIENCY POLICY

LISA RYAN

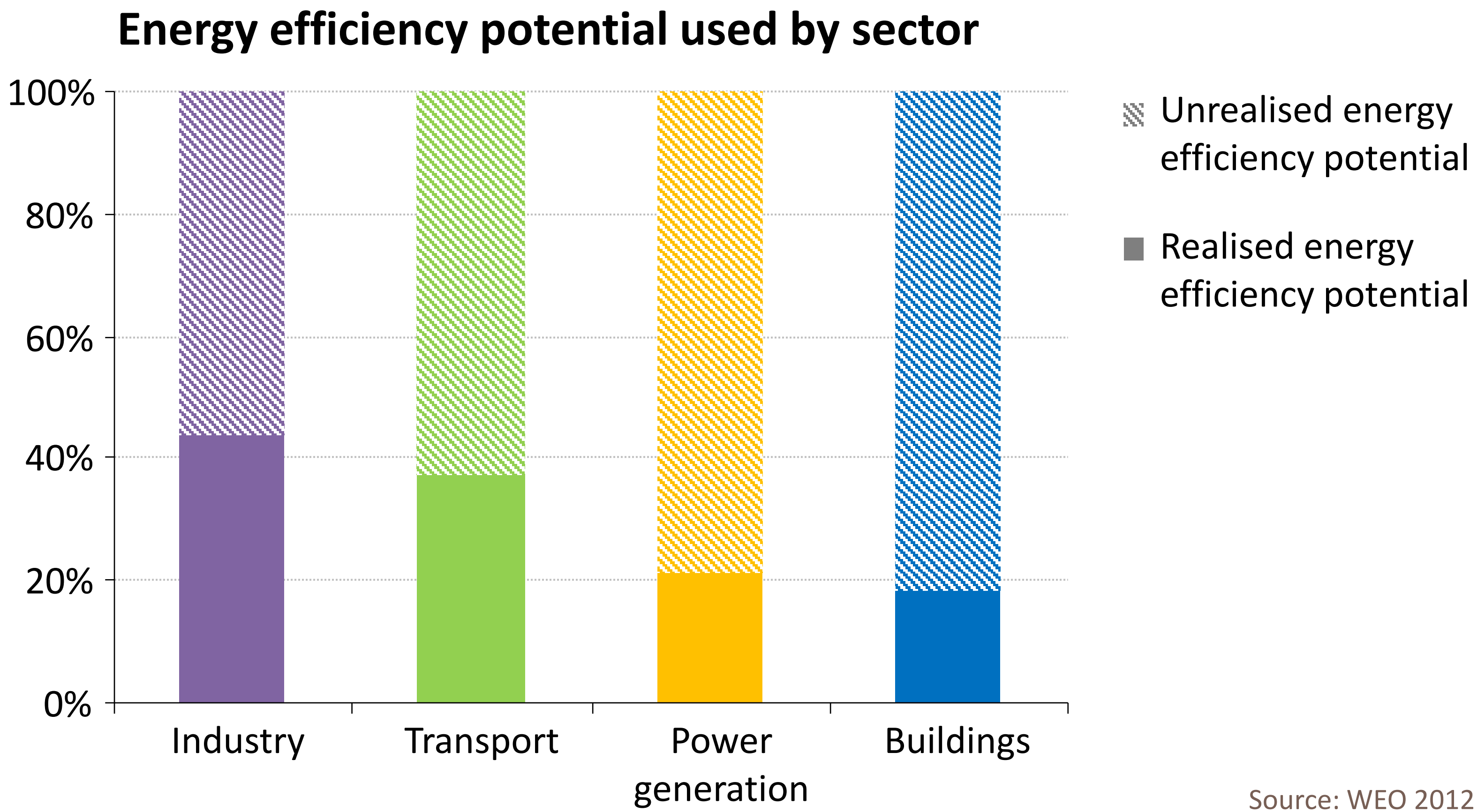
The Energy Efficiency Gap

ZEW, Mannheim, March 13 2014

Outline

- Economic potential of energy efficiency vs current investment
- Barriers and gaps
- Role of economic instruments in energy efficiency policy:
  - Industry
  - Passenger cars
  - Buildings
- When to use economic instruments?
- Summary

Energy efficiency – unrealised potential

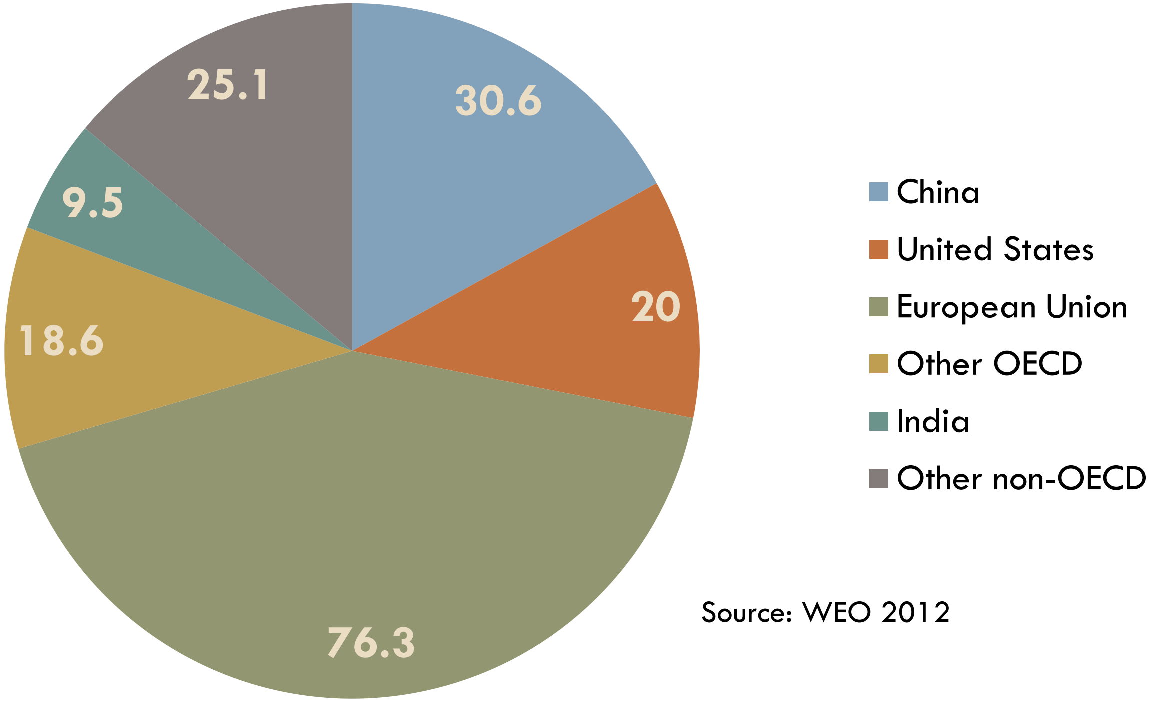


Source: WEO 2012

Two-thirds of the economic potential to improve energy efficiency remains untapped in the period to 2035

Current investment in energy efficiency is more than people think….

Total 2010/11: USD 180 billion

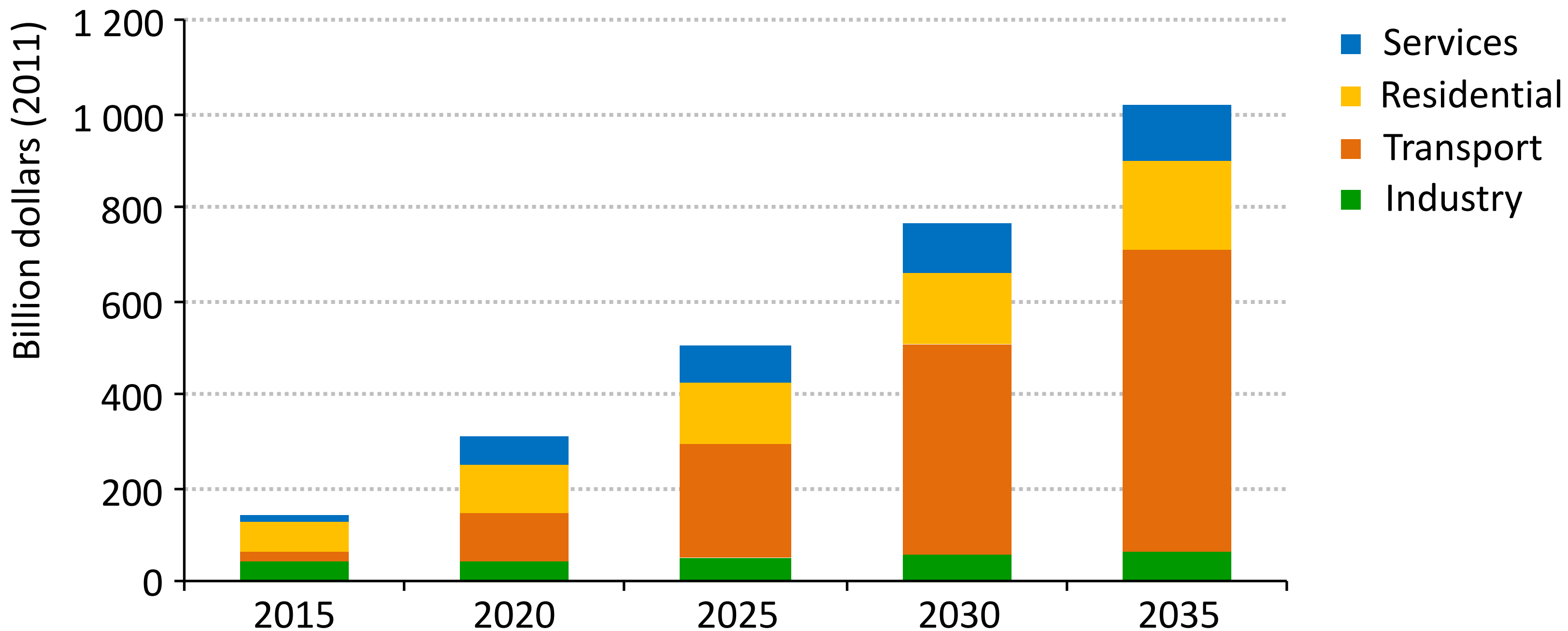


Source: WEO 2012

…..but is not enough to realise the economic potential of energy efficiency.

…but not enough to unlock energy efficiency's potential

Additional annual investments required in end-use efficiency



Source: WEO 2012

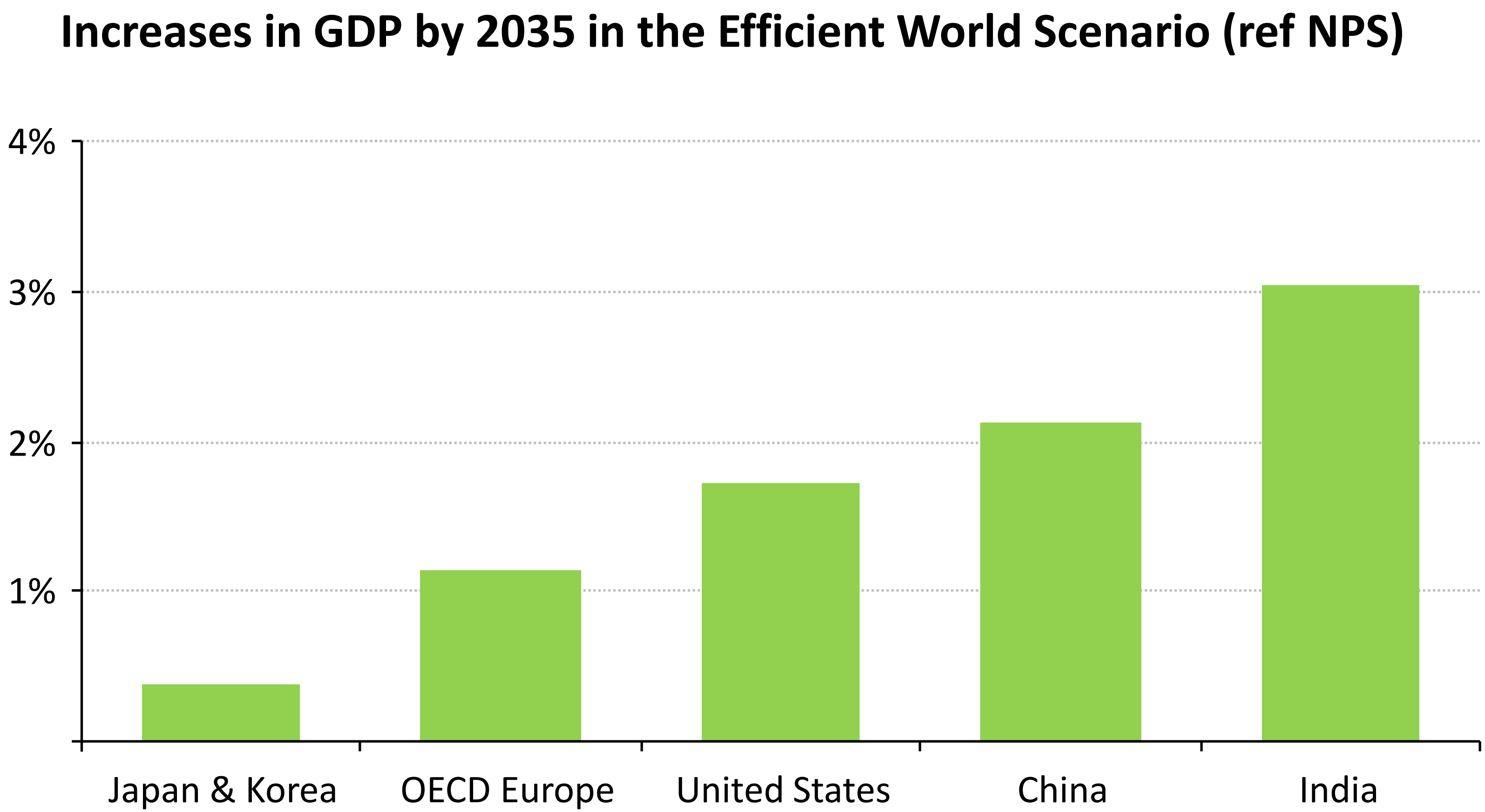
Additional investments required in end-use efficiency are $11.8 trillion over 2012-2035

Multiple Benefits of EE

Source: Ryan and Campbell, 2012

....need to be valued

Energy efficiency yields increased economic growth



Source: WEO 2012

Outline

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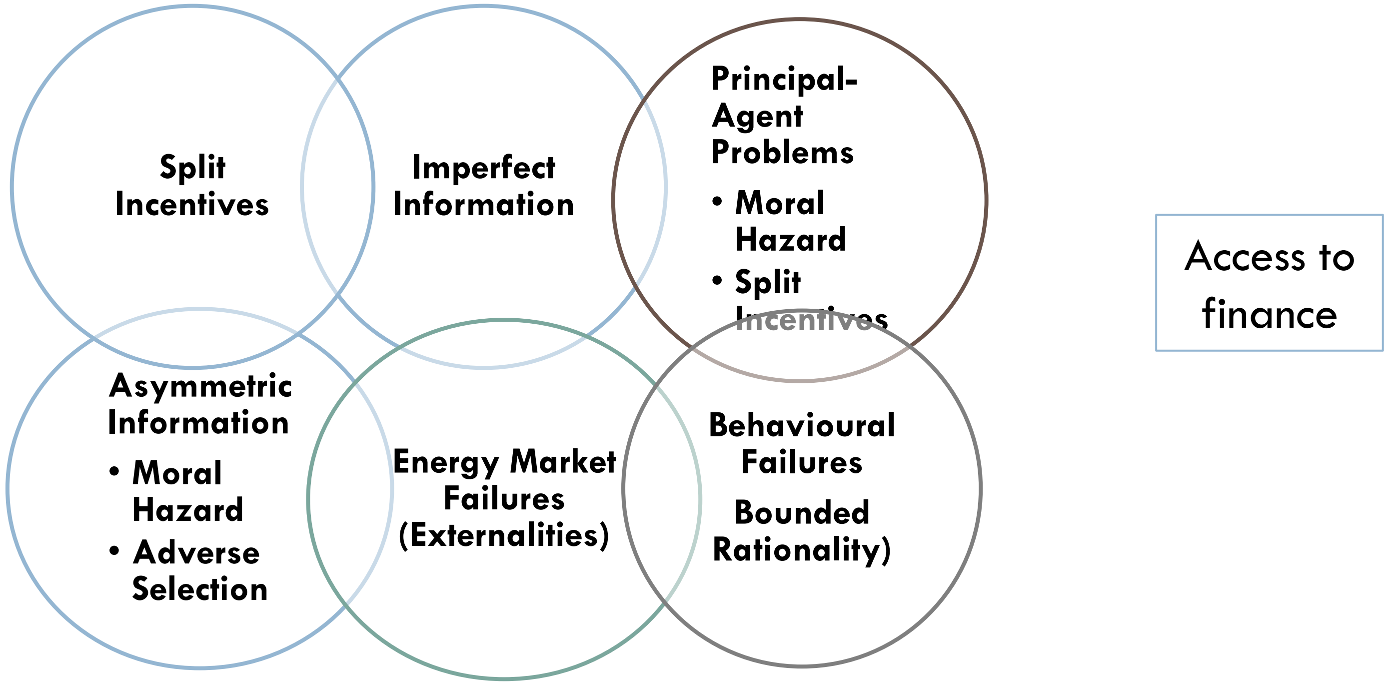
The EE challenge — why so much remains untapped?

- **Externalities**
- **Principal agent problem**
  - Split incentives
  - Absence of clear legal responsibility
- **Information failure**
  - Benefits of EE
  - Lack of training
- **Financial barriers to access to capital**
  - Low energy prices
  - Initial cost
  - Perceived high risk
  - Lack of adequate collateral
  - High uncertainty
  - Small size of the projects, high transaction costs
  - Information failure in finance sector
- **Behavioural issues**
  - Bounded rationality
  - Inertia
  - Myopia
- **Transaction costs**
  - Hassle factor

Market failures in energy efficiency action



- Price important for removing certain barriers, e.g. negative externalities
- However, informational failures and principal-agent problems can prevent price signal from reaching consumers

Example: Appliances electricity use

- Extent of Market failures
  - Present in both technology and use
  - Principal-Agent (i.e. landlord-tenant) problems could affect 20% of U.S. tenants;
  - Informational failure: Japanese study shows little awareness of impact of energy efficiency on electricity costs
- Policies to address these – costs and effectiveness
  - Energy/carbon pricing will not solve these issues
  - Standards and labelling programmes have achieved energy savings in IEA countries
  - Standards estimated to be highly cost-effective in the U.S.
  - Real-time informational tools can save 5-12%

EE policy interaction with carbon pricing - appliances

Market failures → Policies ↓	Energy market failures: negative externalities	Principal-agent problems: Split incentives Asymmetric information	Information failures: Insufficient information Inaccessible information Aggregated energy price	Behavioural failures: Bounded rationality
Carbon pricing	H	-	L	-
MEPS	-	H	H	H
Labelling & Informational tools	-	L	H	M

Source: IEA, 2011

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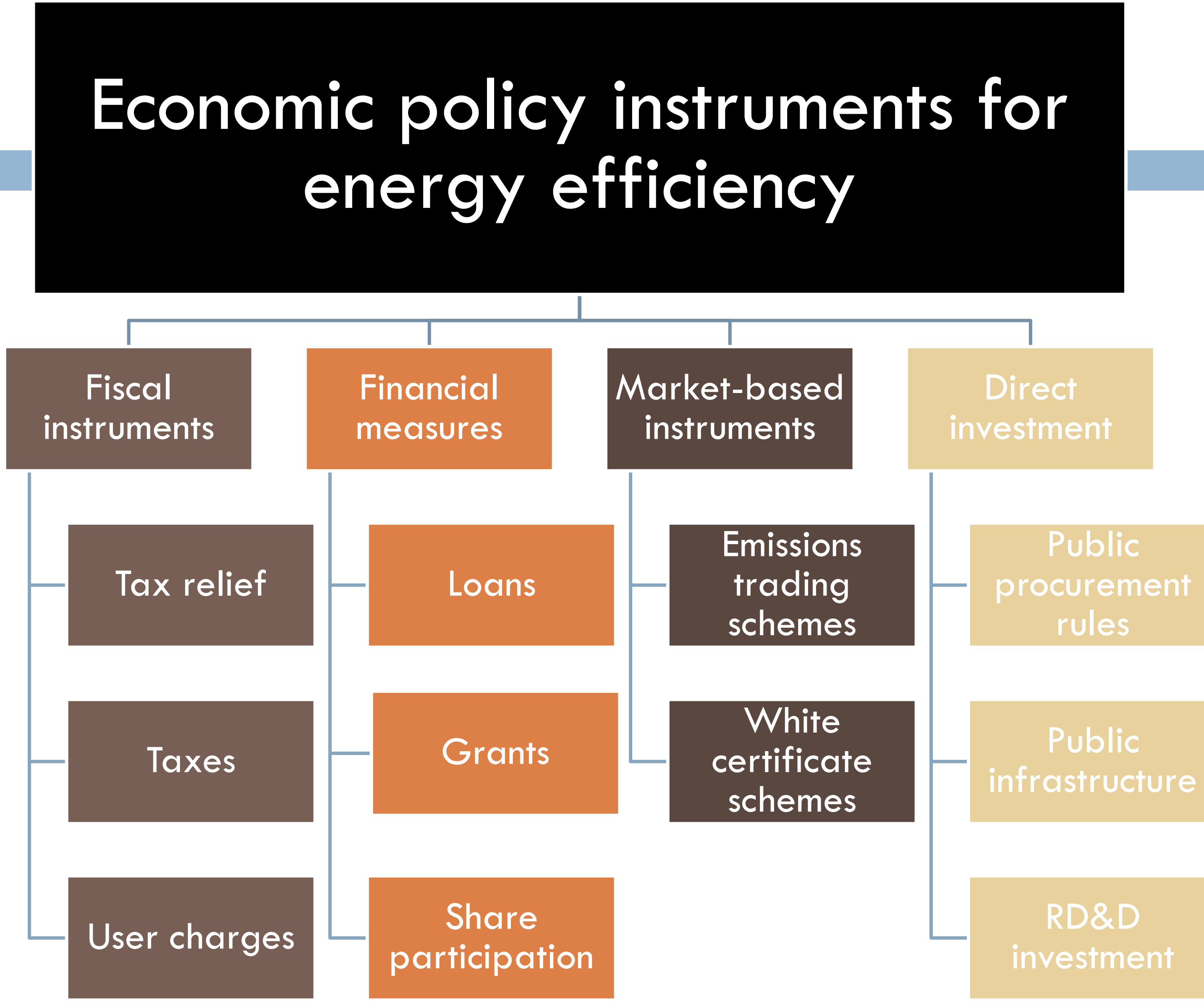
What are the policy options?

- Ultimate goal: sustainable market for EE investment involving private actors
- Main policy categories:
  - ***Regulations*** – mandates, energy performance standards
  - ***Economic Instruments*** – prices and taxes, grants, loans, tax relief (subsidies), trading
  - ***Information measures*** – energy performance labelling, education, awareness, training
  - ***Financial and contractual arrangements*** – PACE, ESCO markets, public procurement contracts



Economic policy instruments for energy efficiency
Fiscal instruments
Tax relief
Taxes
User charges
Financial measures
Loans
Grants
Share participation
Market-based instruments
Emissions trading schemes
White certificate schemes
Direct investment
Public procurement rules
Public infrastructure
RD&D investment

Economic instruments for EE in industry, transport and buildings

Industry	Transport	Buildings
• Tax relief • Audit support • CO_2 emissions trading • Energy management support • R&D incentives • Energy prices • 3rd party finance and ESCOs	• Vehicle tax incentives • Advanced vehicle subsidies • Fuel taxes • User charges • Infrastructure investment • CO_2 emissions trading	• Grants for EE equipment • Loans and grants for refurbishment • Direct investment in social housing • Tax relief • Energy prices • 3rd party finance and ESCOs

Economic evaluation matrix

Category	Criteria	Indicators
Environmental effectiveness	Impact on market	Uptake of programme (units product) Level of awareness/influence (%) Sales of qualifying products (units product)
	Energy savings	Gross energy saved (kWh or toe) Gross CO_2 emissions (tCO2)
	Rebound effect	Increase in sales of energy using equipment (%) Increase in use of energy efficient technologies (%)
Economic efficiency	Free-ridership	Share of tax incentives to purchasers who would have bought the energy efficient equipment anyway (%) Multiplier effects (%)
	Costs	Value of awarded tax incentives Administrative costs (€) Total costs (€) Cost-effectiveness = total costs/energy saved (€/kWh)
	Policy interaction	Qualitative analysis of policies
Other criteria	Process features	Ease of administration Transaction and administration costs (€)
	Market distortion	Price changes (Δ€)

Industry tax relief case studies

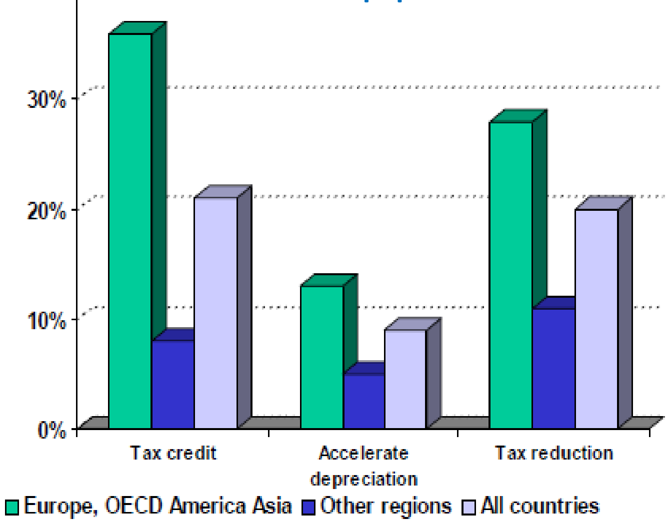
- Tax relief programmes for industrial equipment identified in 10 IEA countries - data received for 6 countries
- Challenges for evaluation:
  - Data availability is limited
  - Very few evaluations to date

Country	*Name of Programme*	*Incentive details*	*Dates of programme*
BELGIUM	*Tax deduction for energy saving investments*	**Tax relief** 15.5% of investment cost deductible	1983 - ongoing
CANADA	*Accelerated Capital Cost Allowance for Efficient and Renewable Energy Generation*	**Accelerated Depreciation** Between 30% - 50% write off per year	1996- ongoing
FRANCE	*Amortisation Law for Energy Saving Equipment*	**Accelerated Depreciation** 100% write off in the first year of purchase	1991 - ongoing
IRELAND	*Accelerated Capital Cost Allowance Scheme*	**Accelerated Depreciation** 100% write-off in the first year of purchase	Oct 2008- Dec 2012
NETHERLANDS	*Energy investment Allowance (EIA)*	**Tax relief** 44% of investment cost deductible from profits	1997 - ongoing
UNITED KINGDOM	*Enhanced Capital Cost Allowance Scheme*	**Accelerated Depreciation** 100% write-off in the first year of purchase	2001 - ongoing

Results of evaluation– 3 case studies

- Effectiveness
  - Gross energy saved:
    0.5 – 1.1% total energy consumptic
  - Free-ridership: 25 – 70%
- Economic efficiency
  - Total costs: €1 – €67 million

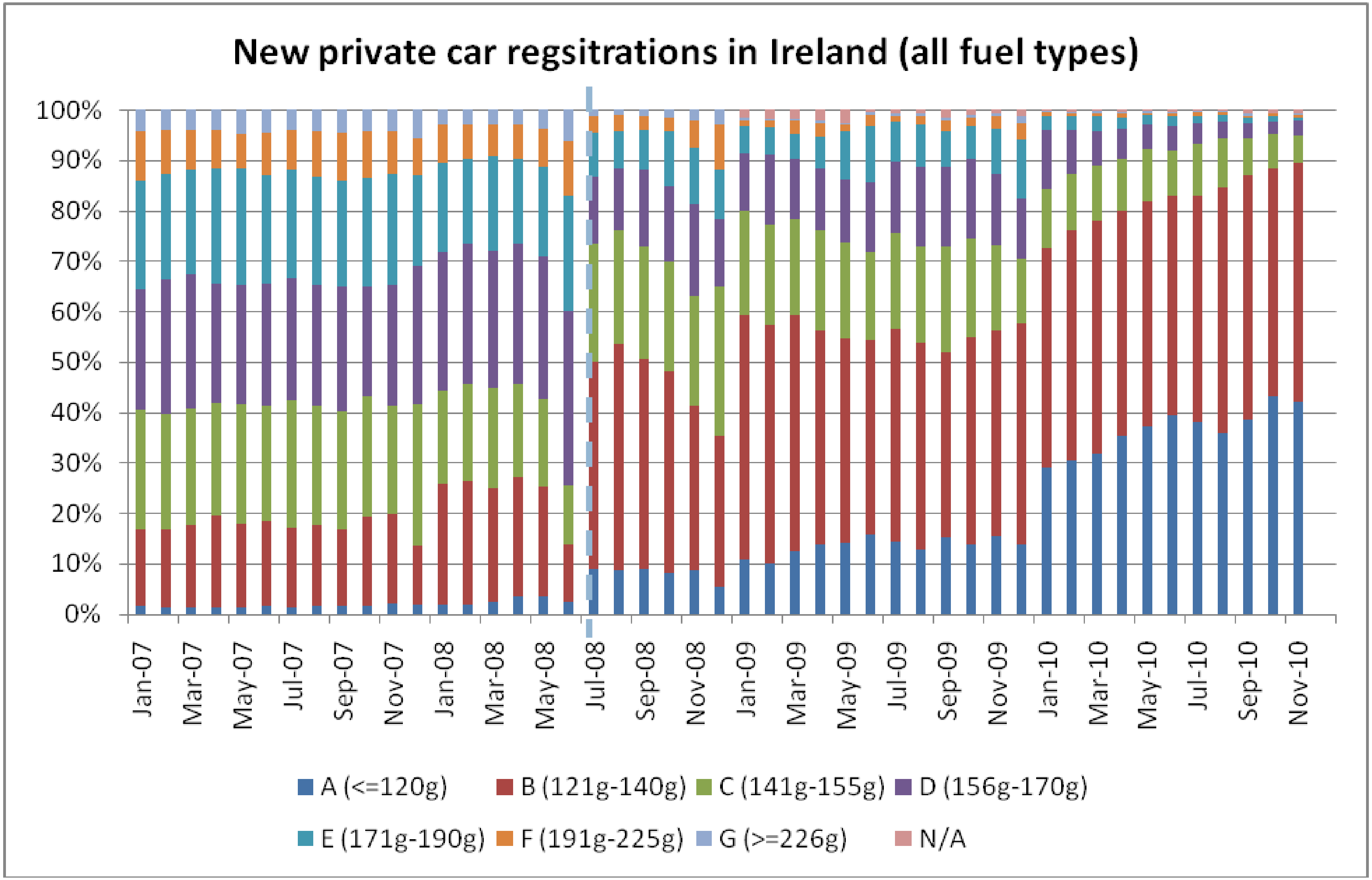
OECD countries with fiscal incentives for energy efficient equipment



Source: World Energy Council, 2008

  - Net cost-effectiveness: €0.002 – 0.036 per kWh saved
- Policy interaction: Yes, with ETS
- Process
  - Governance issues – multiple agencies administering

Passenger car case studies: Effect of vehicle CO_2 taxes



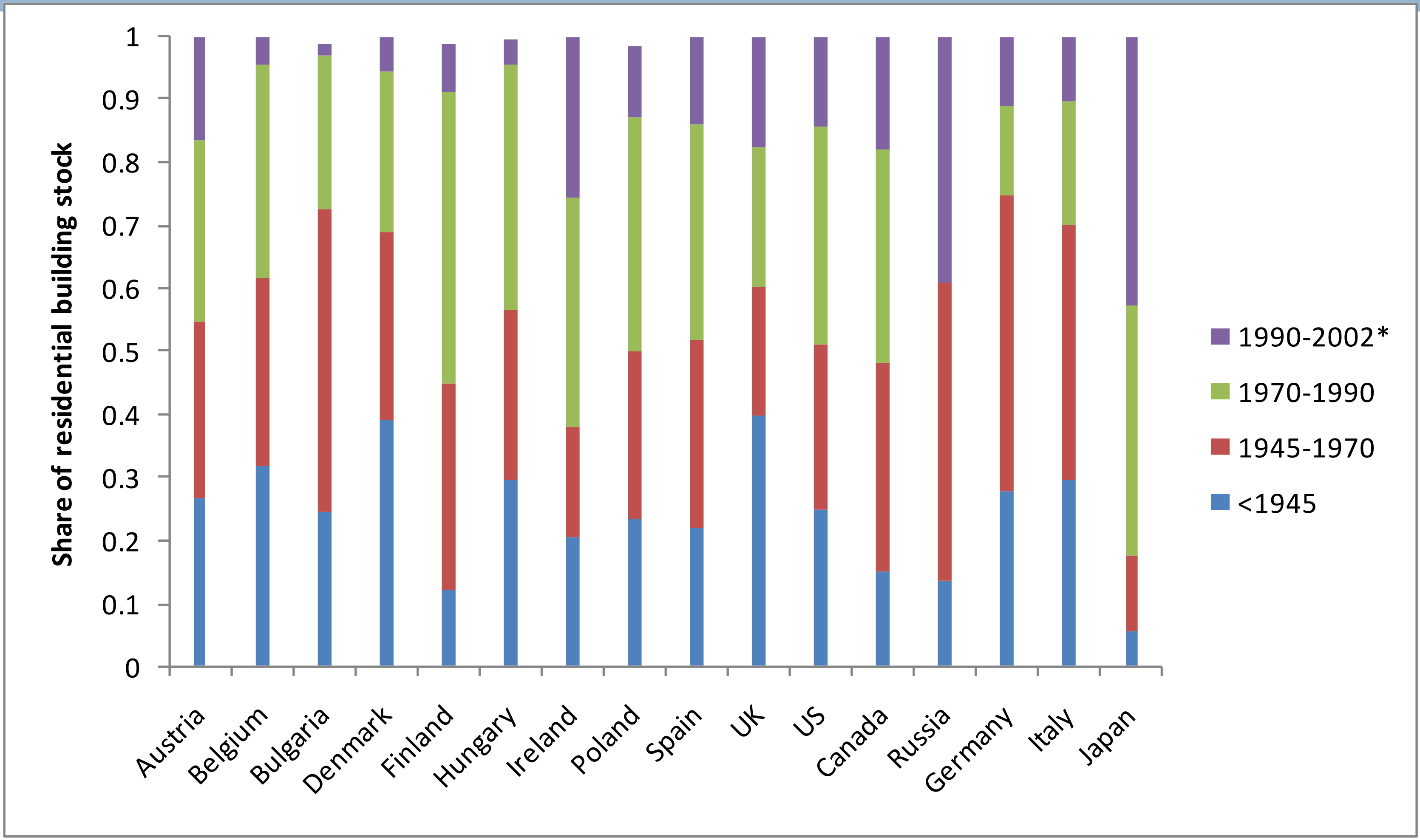
Results of passenger car evaluation – 5 case studies

- Shift to CO2- and FE-based vehicle taxes: 2001 (UK), 2007 (Dk, No), 2008 (F, Ire)
- Effectiveness (change 2005-2009):
  - CO2 per new car sold: 11-15% reduction
  - Rebound effect: None, average -3% VMT
  - Free-ridership: N/A
  - Total new car CO2 (including sales, VMT): average -34%
- Efficiency
  - Total costs: depending on programme, perhaps none
- Policy interaction: Yes, fuel prices, economic recession

Energy efficiency in buildings – key data IEA countries

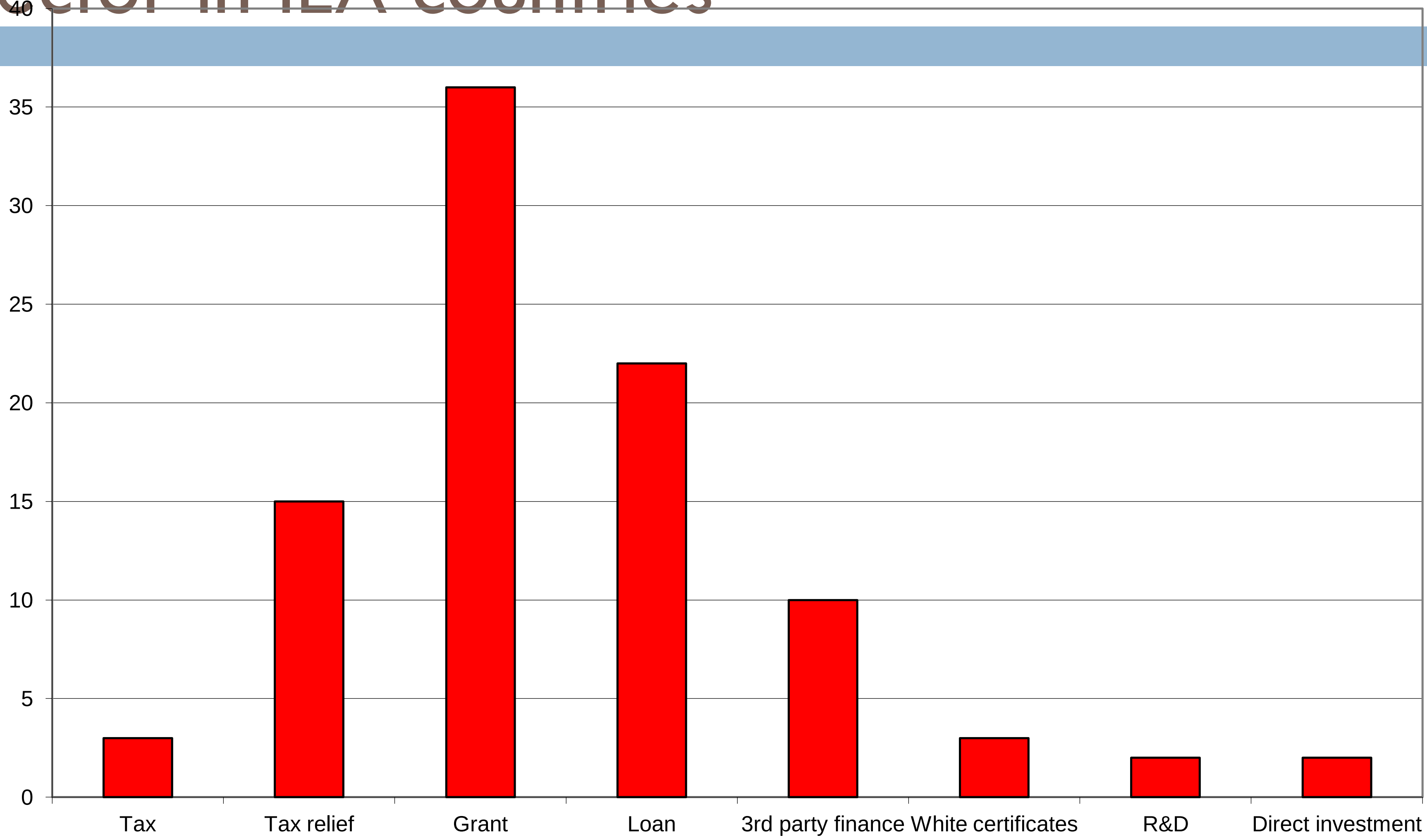
- 32% global final energy consumed in buildings
- 2/3:1/3 split between residential:commercial buildings
- Approx 50% buildings in IEA countries pre-building codes
- Average energy consumption ~ 230kWh per m2
- EU 2020 target for new buildings - 50 kWh/m2/yr
- New buildings share low - < 2%; renovation of existing buildings < 1%/yr
- Target for building stock – 50kWh/m2/yr by 2050? Not all buildings will make it!

Residential building stock in selected countries by vintage



Source: IEA, 2012

Economic instruments in the buildings sector in IEA countries



Residential buildings case studies

Taxes	Tax incentives	Grants	Loans (finance)
Denmark Sweden	France Italy	Sweden Ireland Canada France	Germany USA France Australia

Findings from review of case studies

- Nearly all IEA countries have at least one economic instrument for energy-efficient buildings – but not tied to level of energy performance
- More than one third are (unambitious) grants to owners; loans and tax relief are also widely used – few evaluated
- Policies and capital to facilitate 3rd party finance is a more recent phenomenon and likely to grow. Will be needed to transition to low carbon buildings.
- Increasing evidence of positive impact on macroeconomy and public budgets

Outline

- Economic potential of energy efficiency vs current investment
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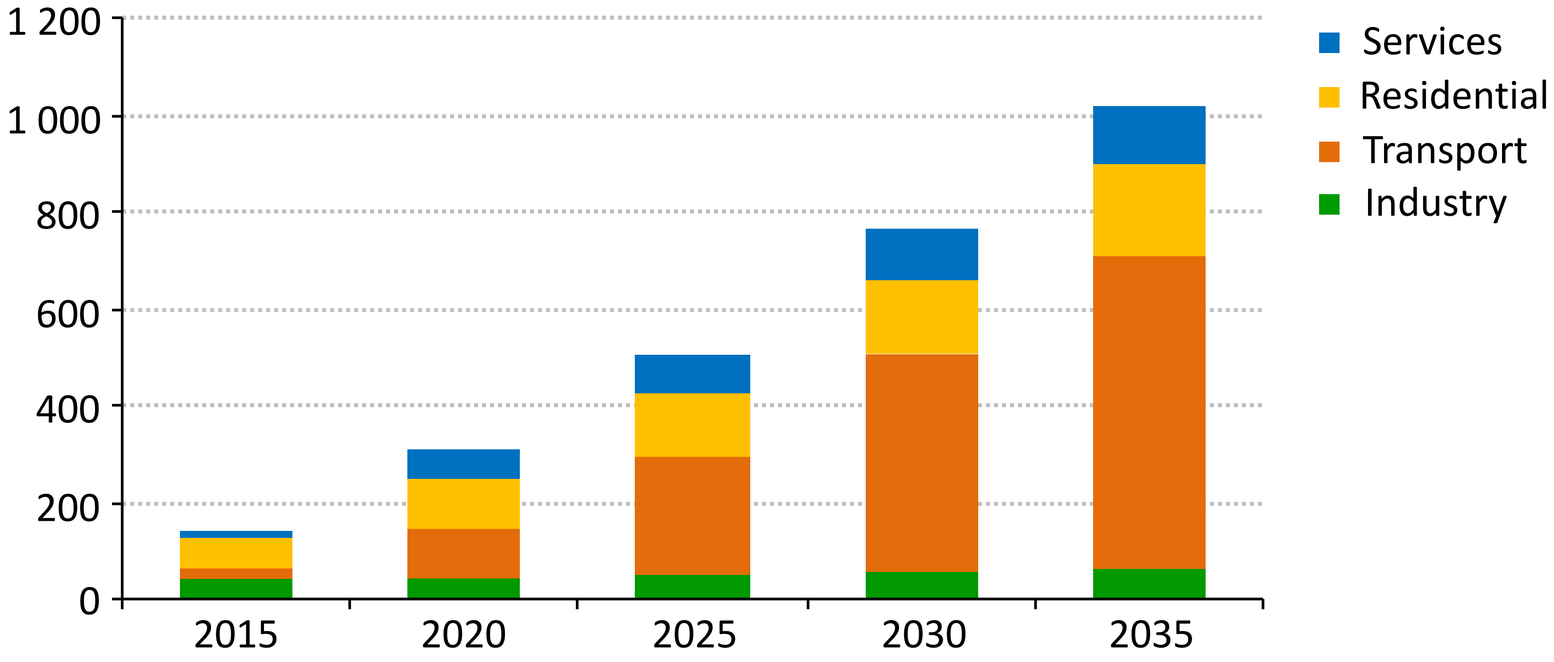
How are we doing?

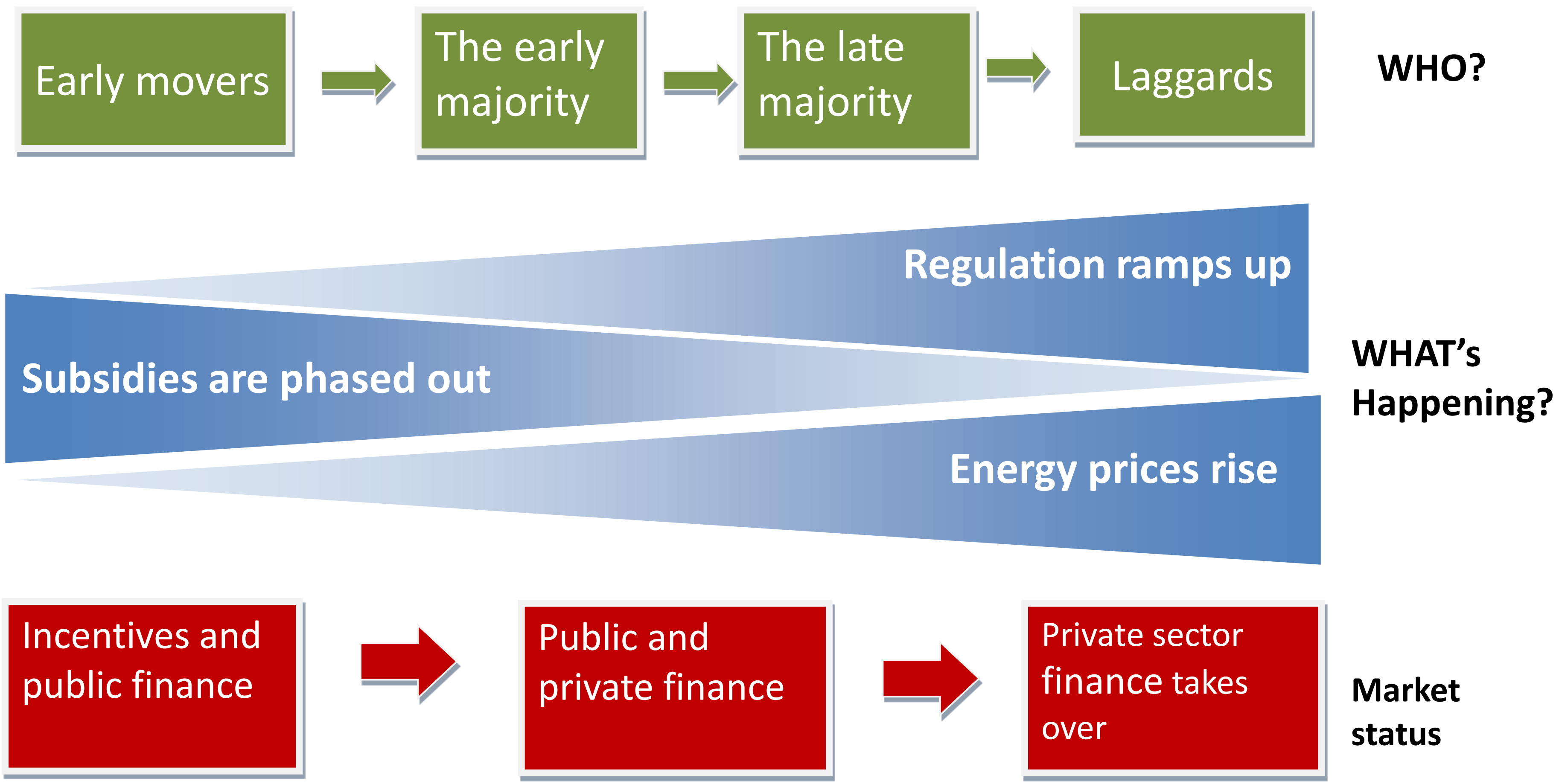
- First instinct – subsidy – grants etc
- Scale of investment finance needed won't work
- Other ideas? Involving the private sector…



Overcoming the barriers

Barriers	Policy options
Externalities	Remove energy subsidies, carbon prices
Split incentives	Regulation, market reform, incentives
Lack of awareness	Targeted information, training
Lack of capacity	Training, technical assistance
Inertia	Regulations, financial incentives
Higher initial cost of EE technologies	Incentives
Perceived high risk	Incentives; risk guarantees
Lack of adequate collateral	Risk guarantees
Small size of the projects, high transaction costs	Clustering through banks
High uncertainty	Measurement protocols, better information

Get timing and mix of policy instruments right!



Public budgets – positive or negative impact?

- Energy efficiency programmes not only impacts on public expenditure
- Revenue impacts may outweigh expenditure:
  - Excise duty
  - Sales tax
  - Jobs
  - Spending
  - Income effects
  - Public health budget
- <u>Not</u> estimated as part of policy appraisal

Summary

- Current level of investment in energy efficiency far below scale needed to reach ambitious targets although significant net benefits
- Government intervention justified
- Economic instruments essential but not alone to achieve targets
- Public budget impacts need more analysis
- Timing and mix of policy mix need to be right to stimulate market to invest in energy efficiency
- Regulations likely necessary to catch laggards

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Further reading:

Ryan *et al*. (2011) Energy efficiency and carbon pricing.

Hilke, A. and L. Ryan (2012), Mobilising investment in energy efficiency: Economic instruments for low energy buildings.

Ryan, L. and N. Campbell (2014), A handbook on estimating the multiple benefits of energy efficiency measures (Forthcoming).

IEA (2013) Energy Efficiency Market Report 2013, OECD/IEA, Paris.

Myths of Conservation (Programs)

Franz Wirl (Univ. of Vienna)

The Energy Efficiency Gap: Reasons and Implications
March 12-13, 2014, at ZEW in Mannheim

Content

- Motivation
- A simple demand model
- Market (policy) failures
- The conservation myth (rebound)
- The myth of the efficiency gap of the
- The problem of incentives (demand and supply)
- Commitment problems

Motto: Popper (1972), "*the main task of the theoretical social sciences is to trace the unintended social repercussions of intentional human actions*."

Motivation

1. **Conservation programs in the US** after PURPA 1978 until mid-90ies (Eric Hirst *more U.S. utilities are running more and larger DSM programs)* spending billions (1991-95: $\$12\ 10^9$) under the assumptions:

•Lovins (1985), *"making gigabucks with negawatts*".

•Eric Hirst (1992), “Thus energy markets do not operate properly and require utility involvement. Utilities can help overcome these barriers and do so at low cost.”

2. **Deregulation** stopped these initiatives in the late 1990-ies.

3. **More Recently**, energy efficiency is one crucial pillar to mitigate global warming. This motivated EU-regulations (e.g., no incandescent bulbs, no high power vacuum cleaners, and the debate about the fuel efficiency of cars), and **white certificates** (forcing utilities to active conservation programs).

Wikipedia, white certificates are documents certifying that a certain reduction of energy consumption has been attained. In most applications, the white certificates are tradable and combined with an obligation to achieve a certain target of energy savings. Under such a system, producers, suppliers or distributors of electricity, gas and oil are required to undertake energy efficiency measures for the final user that are consistent with a pre-defined percentage of their annual energy deliverance. If energy producers do not meet the mandated target for energy consumption they are required to pay a penalty. The white certificates are given to the producers whenever an amount of energy is saved whereupon the producer can use the certificate for their own target compliance or can be sold to (other) parties …. “.

Literature

- **First wave**: **Theory**
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  Lewis Tracy R. and David. E. M. Sappington, Incentives for Conservation and Quality Im-provement by Public Utilities, *American Economic Review* 82, 1321-1340, 1992
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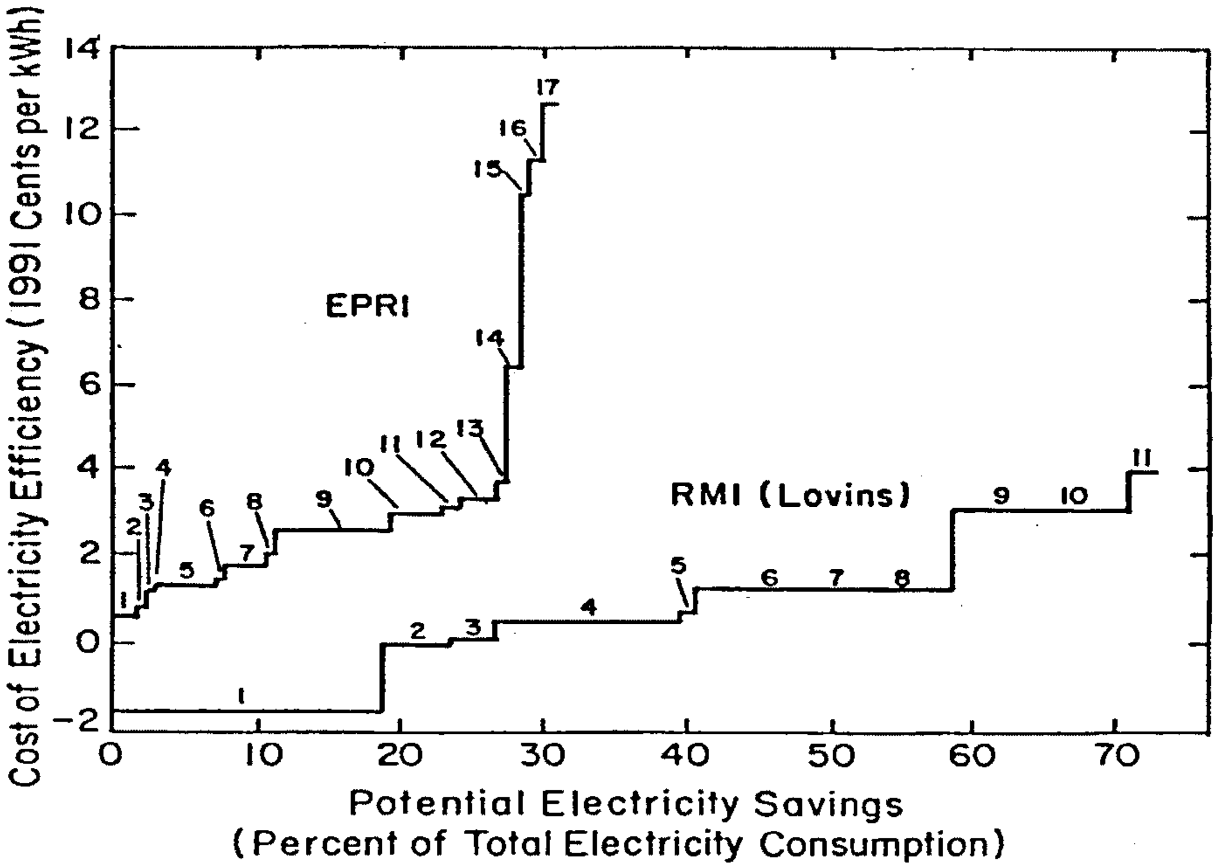
  Assessments
  Nadel Steven, Lessons Learned: A Review of Utility Experience with Conservation and Load Management Programs for Com¬mercial and Industrial Customers, American Council for an Energy-Effi¬cient Economy, 1064-EEED-AEP-88, New York, 1990
  Joskow Paul L. and Donald B. Marron, What Does a Negawatt Really Cost? Evidence from Utility Conservation Programs, *The Energy Journal*, Vol. 13 No. 4, 41-74, 1992.
  Eto Joseph, Edward Vine, Leslie Shown, Richard Sonnenblick and Chris Payne, The Total Cost and Measured Performance of Utility-Sponsored Energy Efficiency Programs, *The Energy Journal* 17/1.
- **Recently**
  Chu Leon Yang and David E. M. Sappington, Motivating energy suppliers to promote energy conservation, *J. of Reg. Econ*.
  Greene David L. (2011), Uncertainly, loss aversion, and markets for energy efficiency, *Energy Economics*
  Joisa Dutra, Flavio M. Menezes,, Xuemei Zheng, Energy Efficiency and Price Regulation

The Myths

Lovins (1985) ***'making gigabucks with negawatts***', with Hirst, "*more U.S. utilities are running more and larger DSM programs*“.
The Economist, March 1st, p 63, ‘AMORY LOVINS was right….’



RMI

1. Lighting
2. Lightning on Heating and Cooling
3. Water Heating
4. Drive Power
5. Electronics
6. Cooling
7. Industrial Process Heat
8. Electrolysis
9. Residental Process Heat
10. Space Heating
11. Water Heating (Solar)

EPRI

1. Industrial Process Heating
2. Residental Lighting
3. Residental Water heating
4. Commercial Water Heating
5. Commercial Lighting
6. Commercial Cooking
7. Commercial Cooling
8. Commercial Refrigeration
9. Industrial Motor Drives
10. Residental Appliances
11. Electrolytics
12. Residental Space Heating
13. Commercial and Industrial Space Heating
14. Commercial Ventilation
15. Commercial Water Heating
16. Residental Cooling
17. Residental Water Heating

The myths

- Higher efficiencies are **the** solution to many energy problems, currently to global warming.

FIGURE 4. ON-ROAD FUEL ECONOMY (FUEL INTENSITY) FOR CARS AND HOUSEHOLD LIGHT TRUCKS

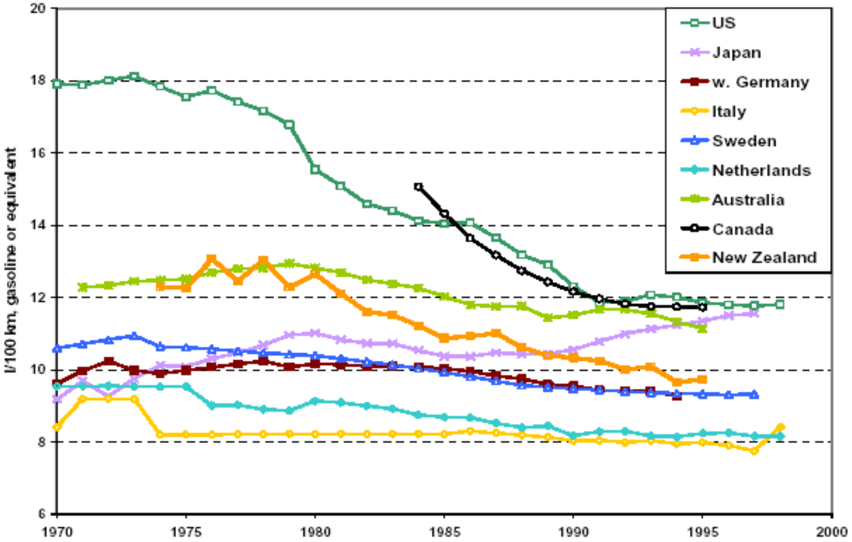
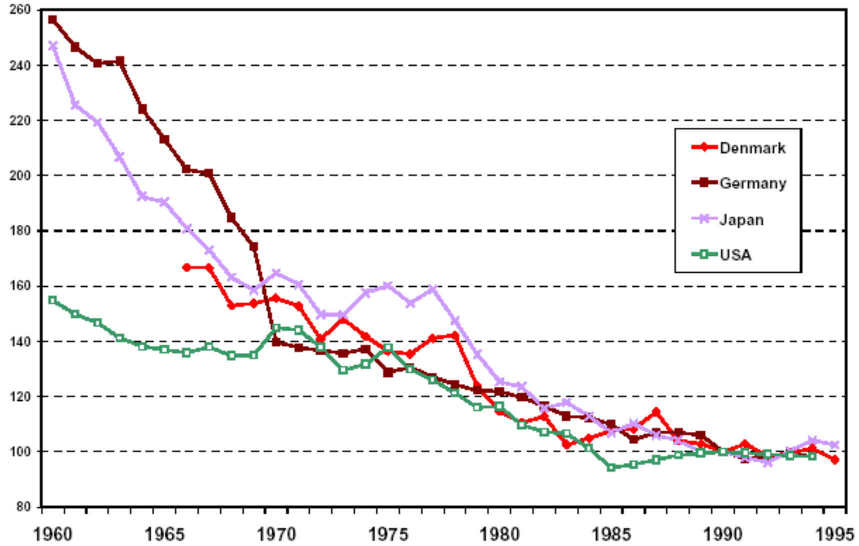


FIGURE 7. LONG-TERM TRENDS IN MANUFACTURING ENERGY INTENSITIES 1990 ENERGY INTENSITY = 100



Jevons, "It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth….Every…improvement of the engine, when effected, does but accelerate a new the consumption of coal"

The myths (cont.)

- Higher efficiencies are **the** solution to many energy and environmental problems and this **economical** (or cheap at least)!
- Yet, energy markets fail:
  1. Consumers are not rational (Hausman 1979) => efficiency gap due to too high discounting, Greene (2011) loss aversion.
  2. Prices are too low (accounting for external costs); **actually a policy failure**.
  3. Therefore technical regulations and/or imposing conservation initiatives on utilities (white certificates) are a necessity.

A simple demand model

Crucial **assumption**: Nobody cares about energy per se but only about **Energy service** (*s*), e.g., lumen hours, miles driven, indoor temperature, etc. Ignorance of quality

Model: General: $s = f(e, \eta)$, e energy, η efficiency

1. $s = \eta e$ – appliances, insulation.
2. $s = e + \eta$ - solar, wind, renewables

Wirl (2014), Taxes versus permits as incentive for the intertemporal supply of a clean technology by a monopoly, *Resource and Energy Economics* **36**, 248-269, 2014. How does the lack of governments to commit restrict the incentives and thereby the supply of clean technologies? Are either emission taxes or emission permits better suited in such a dynamic setting? Although the monopoly can be forced to price taking behavior, **the inability of governments to commit leads to too slow and to too little expansion**.

A simple demand model

Energy service (s), e.g., lumen hours, miles driven, indoor temperature, etc.

$s = \eta e$, e energy, η efficiency.

$U(s)$ Utilty, $U' > 0$, $U'' < 0$, Inada conditions

p energy price, $p < C'$ = marginal (social) cost of kWh => **Market Failure 1**

$K(\eta)$ investment in energy efficiency, $K' > 0$, $K'' > 0$

L life time of equipment

D (subjective) payback time < social payback time R => **Market Failure 2**

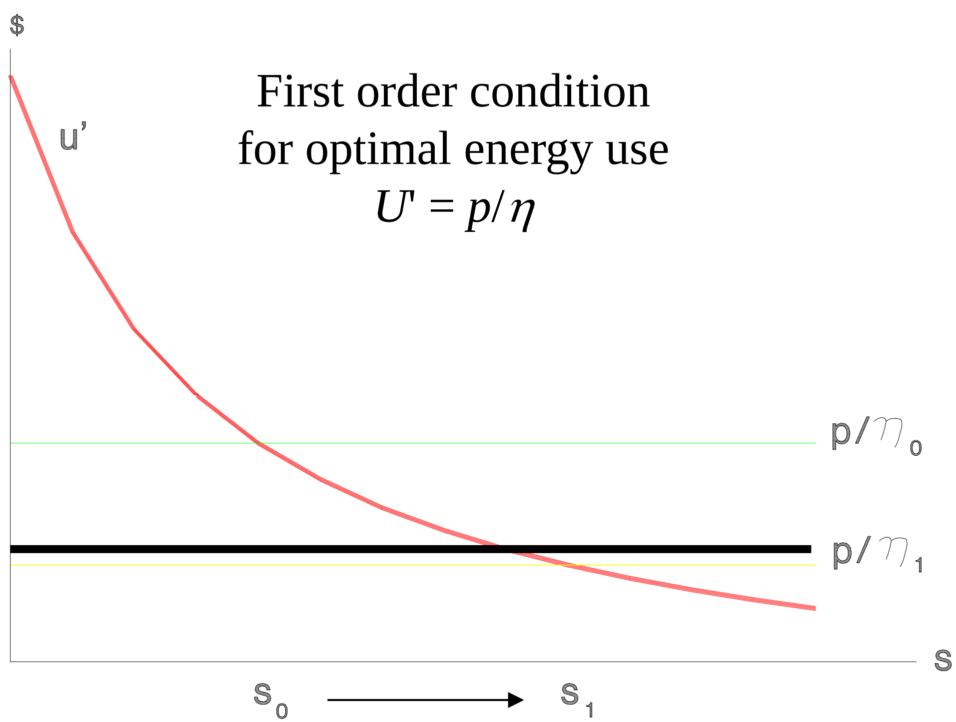
$$D := \int_0^L \exp(-\mathbf{d}t)dt < R := \int_0^L \exp(-\mathbf{r}t)dt$$

Consumers max $D[U(s) - pe] - K(\eta)$

energy: $U' = p/\eta \Rightarrow e = E(\eta, p)$

efficiency: $U'e = \delta K.$

Rebound effect, $e = E(\eta, p)$



Jevons, “It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth….Every…improvement of the engine, when effected, does but accelerate a new the consumption of coal”

More efficient appliances incresae service demand => energy conservation, if at all (see Jevons), falls short of the efficiency improvement, e.g. passive houses & size.

Possible **paradox**: higher efficiency can INCREASE energy demand, e.g., heating single stoves – CH

Rule of Thumb: **Rebound** is

- **small** for services with low demand, e.g., TV, refrigerator
- **substantial** for services with high fuel requirements, e.g., heating, showers, mobility).

Law of unintended consequences - congestion

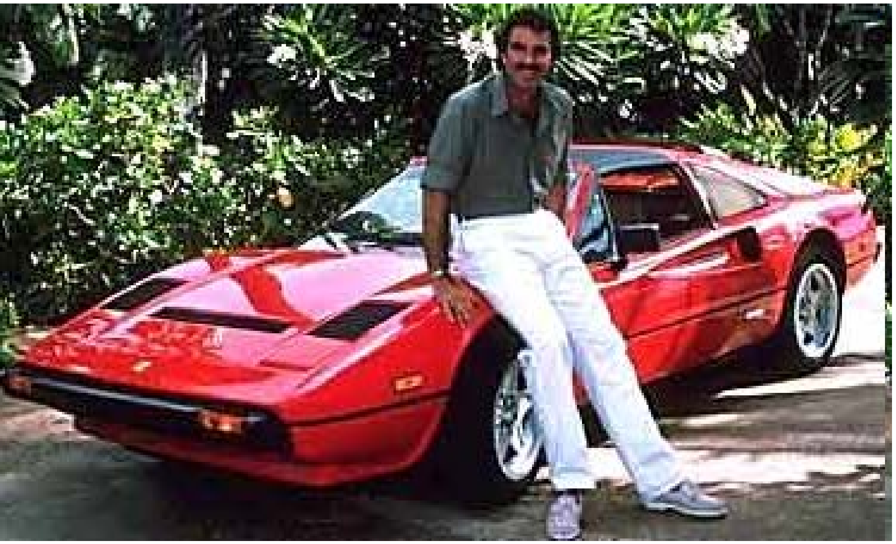
Finally – rebound can work also via quality (e.g. SUVs),

HENCE – Technology alone CANNOT solve the energy problem!

Conjectured rebound effect of DSM programs classified according to appliance and consumers

Program	Rebound effect (conjecture)
HVAC (heating, ventilating, air conditioning):	presumably large, but anyway significant
Construction (new buildings and retrofit):	large.
Lighting, fluorescent and energy saving bulbs:	small for industry & commerce, significant for households.
Appliances (refrigerators, freezers, washing machines, etc.):	modest, largely restricted to upgrading size and acquiring fringe attributes.
Water heating:	large.
Weatherization programs:	large.

Example*



Ferrari GTS
230 hp*, 0-60 mi in 7.3 sec.

The 308 was capable of producing 255 bhp from its 3 liter, V8, carburetor engine. In 1980, a Bosch K-Jetronic fuel injection system was installed due to new emission regulations. This caused the horsepower to drop to around 215 hp, thus making the 308 GTBi the slowest of the 308 series.

In 1981, Ferrari introduced 4 valve heads for the 3 liter V8's. This 308's now became known as 308 GTB/GTS Quattrovalvole. The engine now produced 240 BHP, and with the extra weight that was imposed due to using all-metal rather than fiberglass, the performance and handling was back to where it was when it began production.

Toyota RAV4 2010
269 hp, 0-60 mi in 7.3 sec.
(Soccer mam's car)

Like the Tin Man in "The Wizard of Oz," a body of metal is nothing without a heart. Thankfully, the 2009 Toyota RAV4 -- when fitted with the optional V6 -- has plenty of heart, thanks to 269 horsepower, potent acceleration and a modest appetite for fuel. In fact, this V6 gets about the same fuel economy as some four-cylinder-equipped competitors.

* From Sperling who gives slightly different numbers for the Ferrari than the quote from Wikipedia below.
http://www.almaden.ibm.com/institute/resources/2009/presentations/DanielSperling-AlmadenInstitute2009.pdf

Further rebound effects

- **Direct** : higher energy efficiency lowers the price of that service, and hence increases the service consumption.
- **Indirect**: the lower (marginal) price of the energy service changes the relative prices and therefore affects the consumption of other goods. In addition, there is an income effect: if the total costs for the more efficiently provided service is lower (higher, i.e., if due to regulatory mandate) then real income is increased (reduced).

Assumptions

- Are the assumptions about the two market failures valid?

1. Prices are too low (actually, a **policy failure** given the heavily taxed and regulated energy prices, at least in the EU).
2. Are (if) observed high discount rates and indicator a market failure?

Assumptions

- Are the assumptions about the two market failures valid?

1. Prices are too low (actually a policy failure given the heavily taxed and regulated energy prices, at least in the EU)
2. Are (if) observed high discount rates and indicator a market failure? Payback gap: $D := \int_0^L \exp(-\mathbf{d}t)dt < R := \int_0^L \exp(-\mathbf{r}t)dt$

What about genuine uncertainty of:

- Young people?
- Students?
- Old people?
- Sick people?
- Very mobile professionals
- Governments' lack of commitment (recently Spain PV, passive heating?)

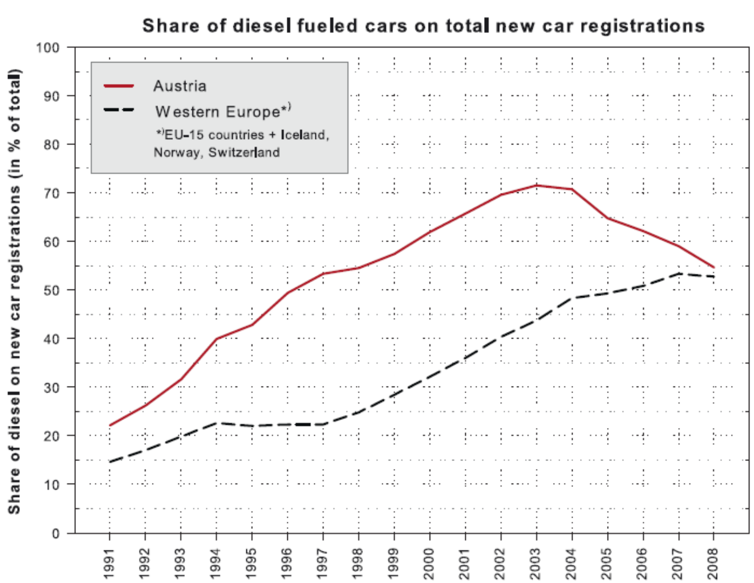
Or about low usages

- Weekend homes?
- Bulbs in cellars, WC, etc.
- Investments with short planning horizon?

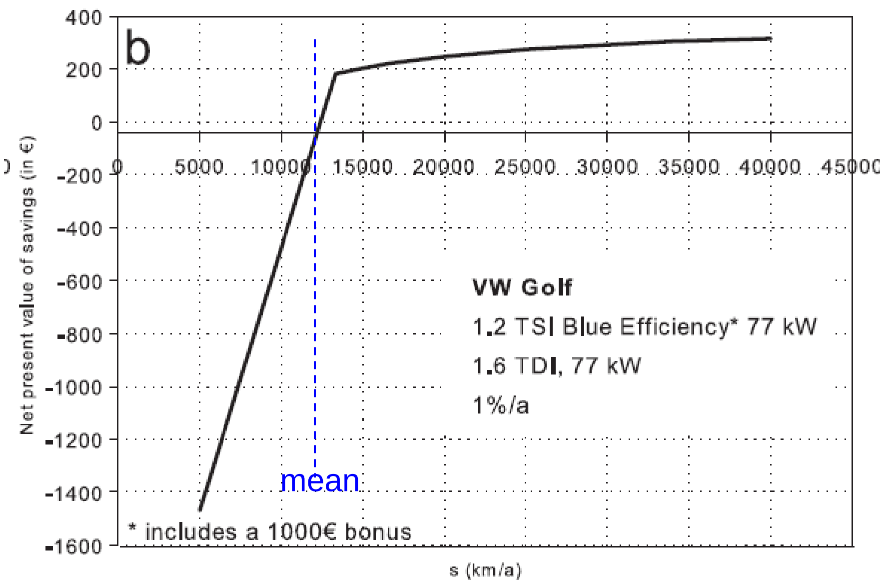
Hayek (1945) "*... an economic actor on average knows better the environment in which he is acting and the probable consequences of his actions than does an outsider, no matter how clever the outsider may be.*"

Is there payback gap at all?
Diesel vs Gasoline cars in Austria

	1999/2000	2003/2004	2005/2006	2007/2008
Average yearly kilometers driven (per automobile)				
Gasoline	12,032	11,950	11,429	11,342
Diesel	15,965	16,334	15,680	15,232
Other		14,011	11,426	9885
Total	13,461	14,142	13,740	13,497



NPV from diesel engine vs mileage



Roland Görlich and Franz Wirl, Interdependencies between Transport Fuel Demand, Efficiency and Quality: An Application to Austria, *Energy Policy* 41, 47-58, 2012.

Assumptions

Although

- too **low prices**, what most would contest today, are by and large a **policy failure** (since prices are regulated), or lack proper internalization,
- and the payback gap may be another myth,

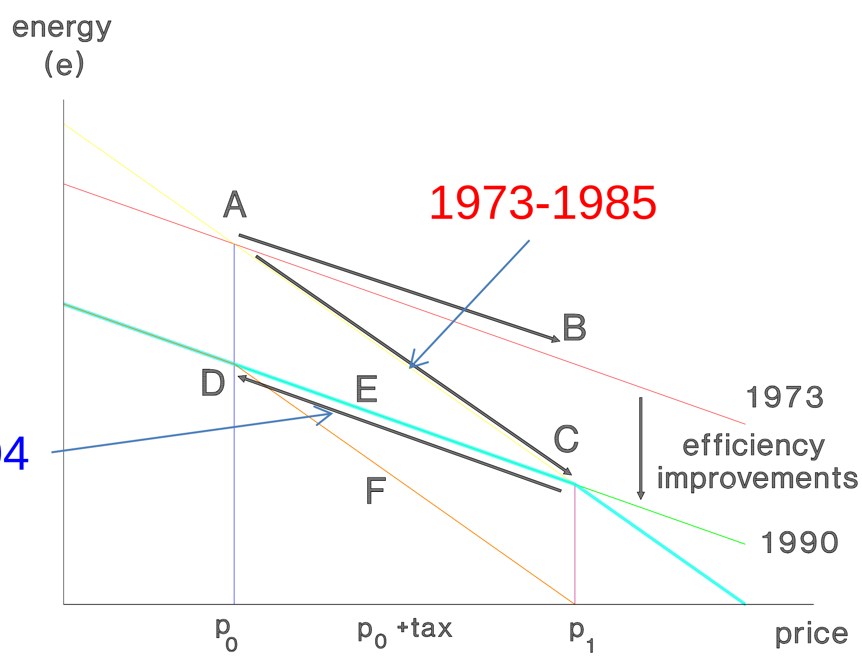
The hypotheses about these two kinds of 'market' failures must be assumed in the following because otherwise it is hard to justify interventions (standards, subsidies).

Incentives

- **Supply** (of efficiency)
  commitment problem
- **Demand** (Consumers)
  utility programs (practice & experience)
  general properties
- **Incentives – general remarks**:
  von Hayek & von Mises vs. Lange, Lerner, Samuelson etc.
  Asymmetric information is a central problem for incentives **3 Nobel prizes** to 8 laureates – Mirrlees und Vickerey, Akerlof, Spence and Stiglitz, and 2007 Hurwicz, Maskin and Myerson.
  Yet Elias Canetti, Voices of Marrakesh.
  Puzzle: Often ignored, primarily in politics

Supply of efficiency

- **Sunk costs** => **history dependent** (NOT asymmetric) demand
- Delays
- Stock effect

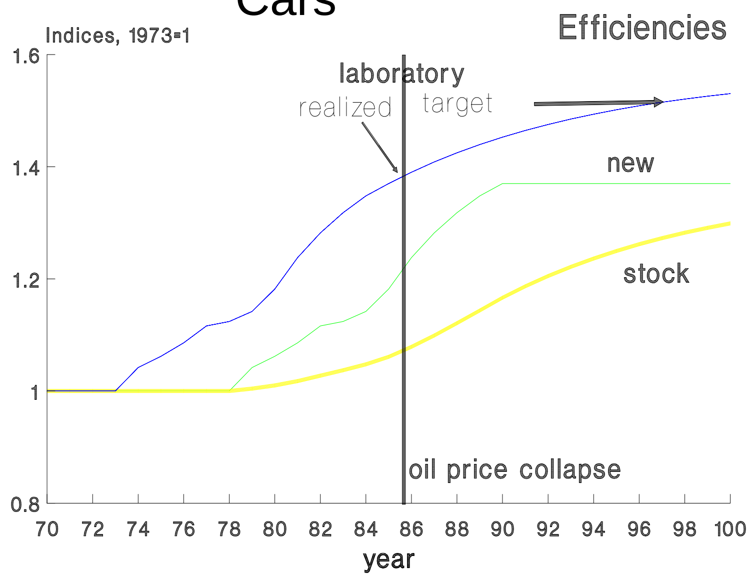


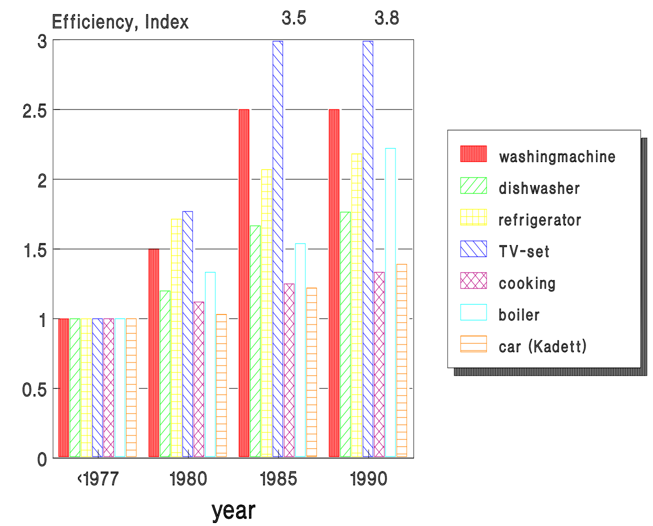
- **Corollary** (i) Global stimulus (ii) prices above ‘digested’ levels
- Commitment problems due to sunk costs

Application - Transport

Technical efficiency improvements

Cars



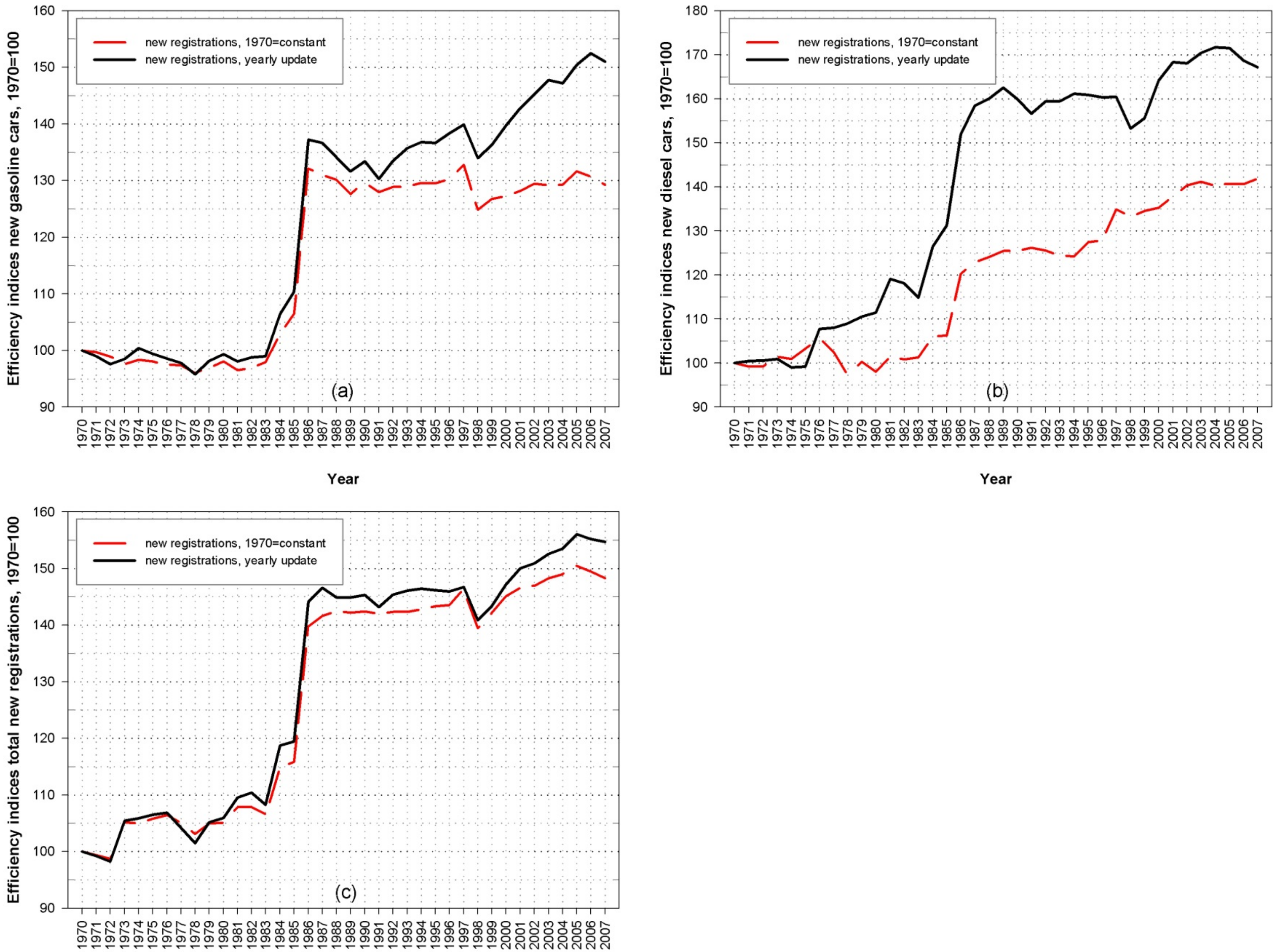


Elasticity estimates 1961-1989

	Symmetric		‘Asymmetric’		
	Price	Income	Price	Income	Efficiency
France	0.73	1.15	0.38	1.47	-0.62
Germany	0.35	1.23	0.31	1.50	-0.69
Italy	0.50	1.27	0.51	1.34	-0.49

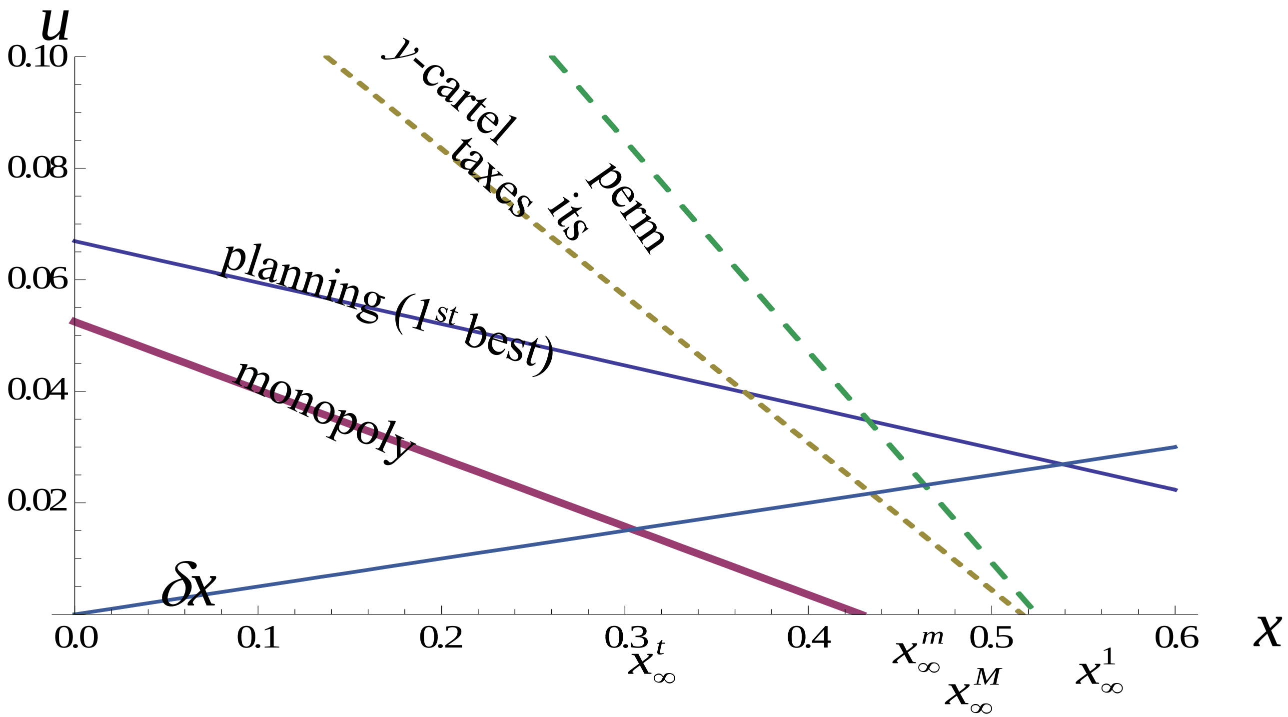
Efficiencies of Cars - update

Efficiency improvements of new cars (gasoline and diesel segment, overall)



Lack of Commitment

Montero Juan-Pablo, A Note on Environmental Policy and Innovation when Governments cannot Commit, *Energy Economics* 33 (Supplement 1) S13--S19, 2011.
Franz Wirl, Taxes versus permits as incentive for the intertemporal supply of a clean technology by a monopoly, *Resource and Energy Economics* 36, 248-269, 2014.



Utility conservation programs

- Although it is the consumer who chooses the efficiency, this responsibility is often (in my opinion, mis-) placed into the hands of utilities.
  1. With PURPA, USA, 1978
  2. Recently white certificates in the EU
  3. Prominent in the academic literature with Lewis-Sappington 1992, and Sappington also recently.
- This requires assumption about utility regulation like, Price caps, Rate of return regulation, incentives (e.g., shared savings)

Utility Programs – Price Caps

Least cost planning

Lovins:
negawatt(h) = kWh,
hence should be treated alike

Implicit Assumptions:
Consumers' efficiency $\boldsymbol{\eta_0}$ is given,

$\eta := \eta_0 + \Delta\eta$,
$\Delta\eta$ = conservation due to program

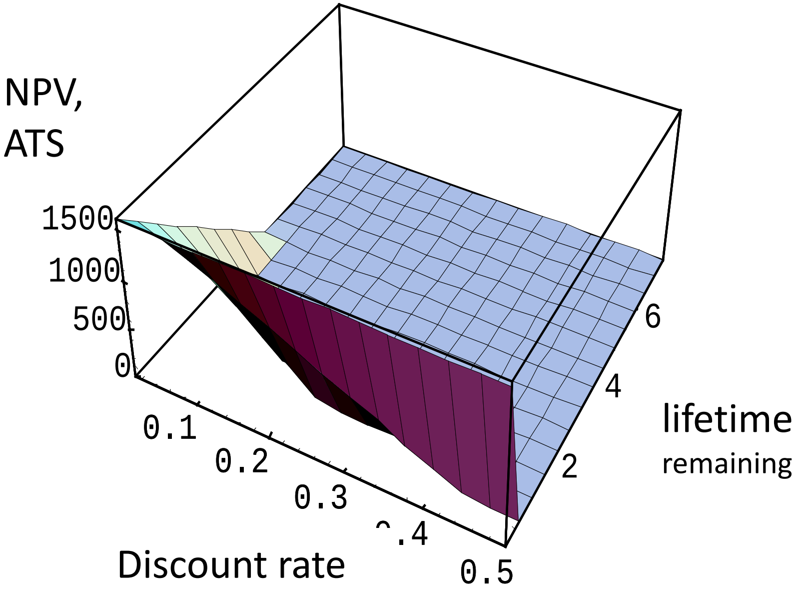
Price cap regulation;
utilities are indifferent if:
price = average costs.
$\Rightarrow$criterion:
cost of negawatt = (MC – *p*)

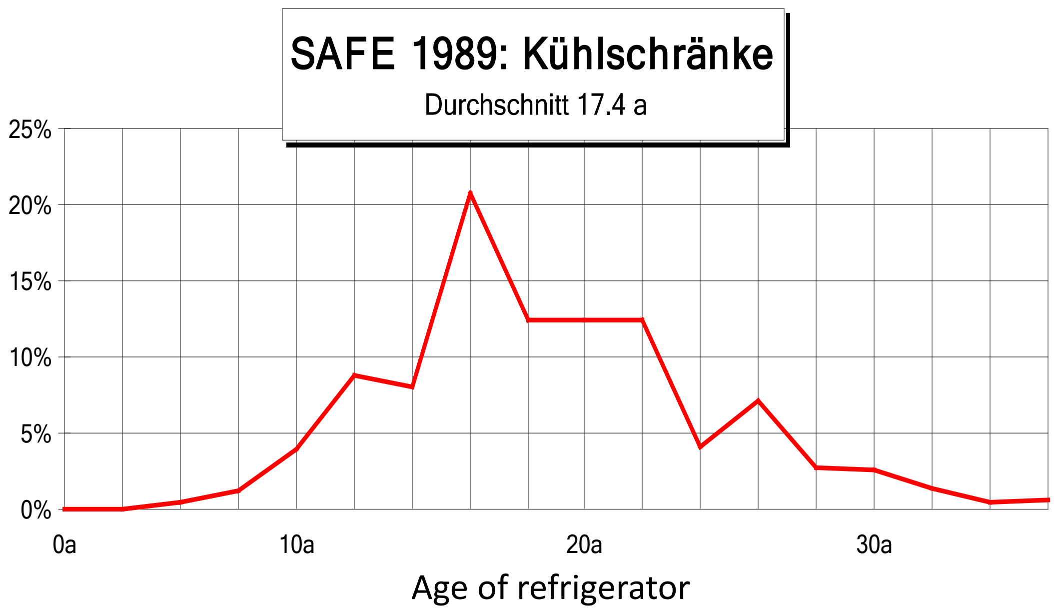
Program	Description
Audits	on site computerized energy audits for a nominal fee or free of charge.
Other information	brochures, home energy rating, hot lines, videos, etc.
Technical assistance	on energy efficiency, e.g., to individuals but also to the builders of homes.
Appliance rebates	are paid by the utility for 'efficient' appliances, air conditioning, heating motors, lighting, etc.
Loans	supplemental grants, or grants at reduced rates, for conservation measures
Payments for kWhs saved	'performance contracting' pays for kWhs saved;
Bidding	simultaneously for demand-side and/or supply-side resources
Rate reductions	lower electricity tariffs for complying with particular efficiency standards
Installation	of conservation measures for free by the utility

Adverse Selection by subsidies

Incentives – subsidies
Example SAFE, Refrigerator
annual saving = 200 ATS/a,
Costs = 8000 ATS, L = 15a,
Subsidy (20%) = 1600 S.

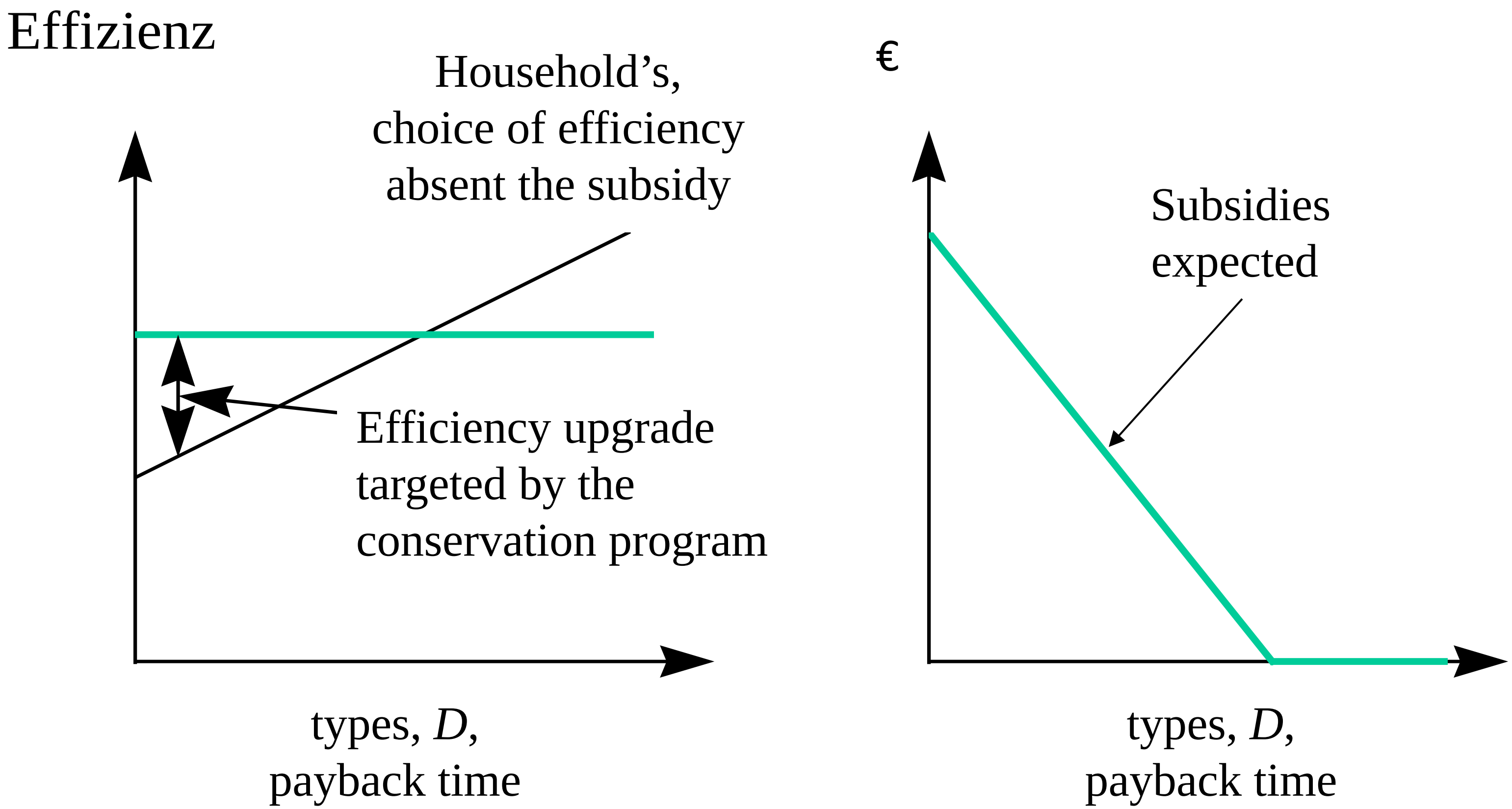
Private Information:
remaining life time
subjective discount rate





Implications:
- Pool of participants is **different** from the average!
- Many free riders!
- Conservation lasts shorter than engineers assume (L)

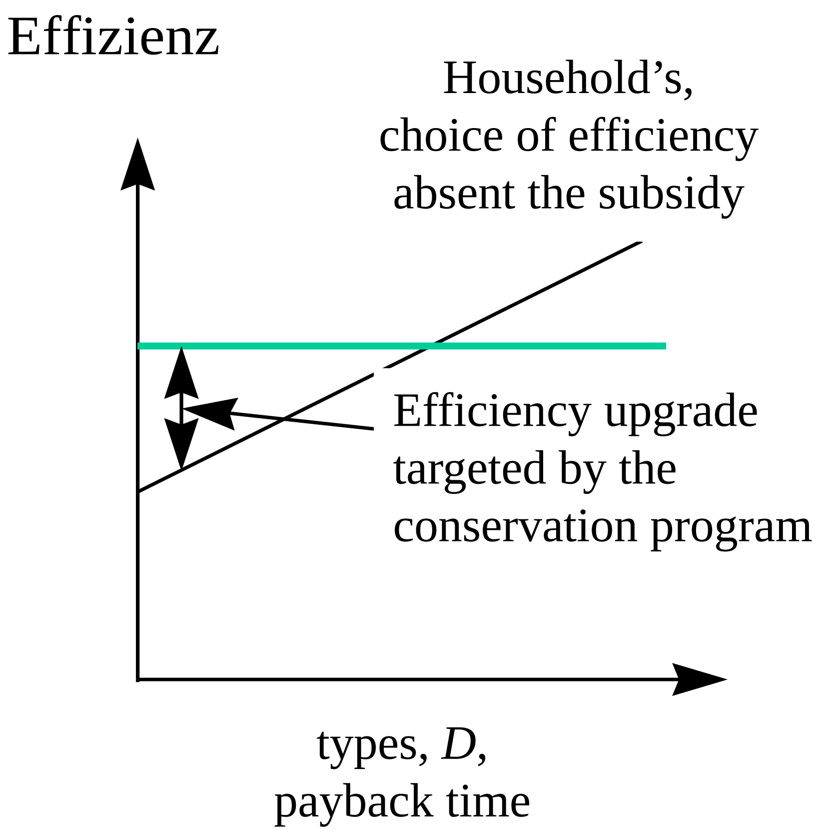
Least cost planning ignoring *Morale Hazard*

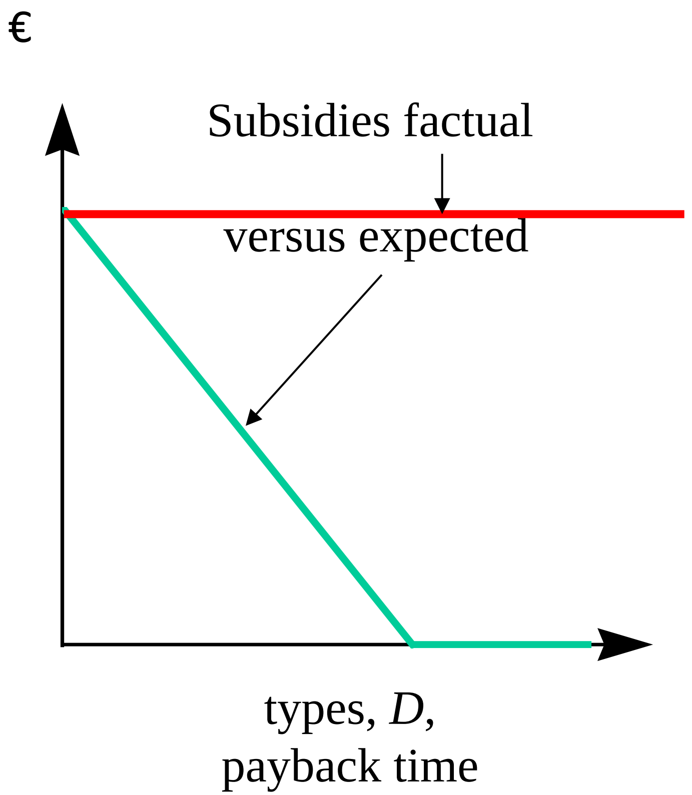


Least cost planning accounting for Morale Hazard

Implication on participation:

subsidies intended for inefficient households **crowd out** the efforts of the efficient households with a high ‘D‘.





Optimal program given private information of consumers about payback time *t*

Consumers
t private

$$W(\eta,t) = t[\max_{e} u(e\eta) - pe] - K(\eta)$$

Utility
price capped

$$\max_{\eta(t),\tau(t)} U^p := \int_{t_0}^{t_1} [V - \tau]dF = \int_{t_0}^{t_1} [t_1(p - c)E(\eta(t),p) - \tau(t)]f(t)dt$$

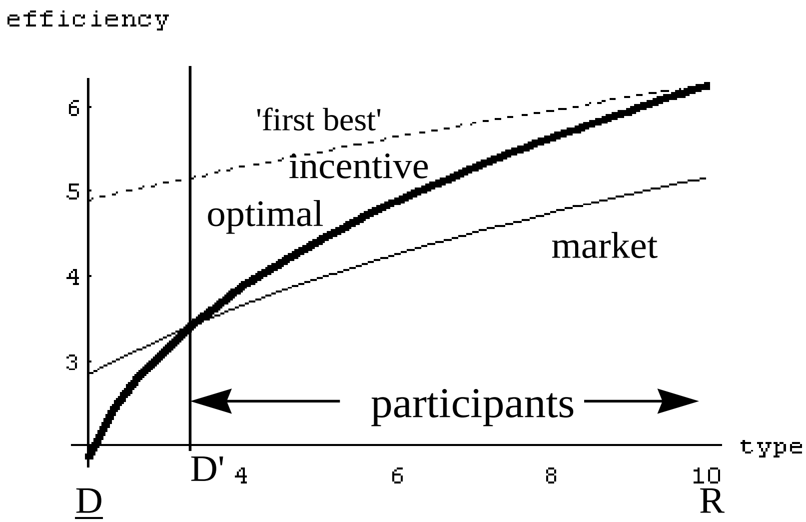
IR constraint

$$W(\eta^m(t),t) \le U^a(\eta,t,\tau) := W(\eta(t),t) + \tau(t)$$

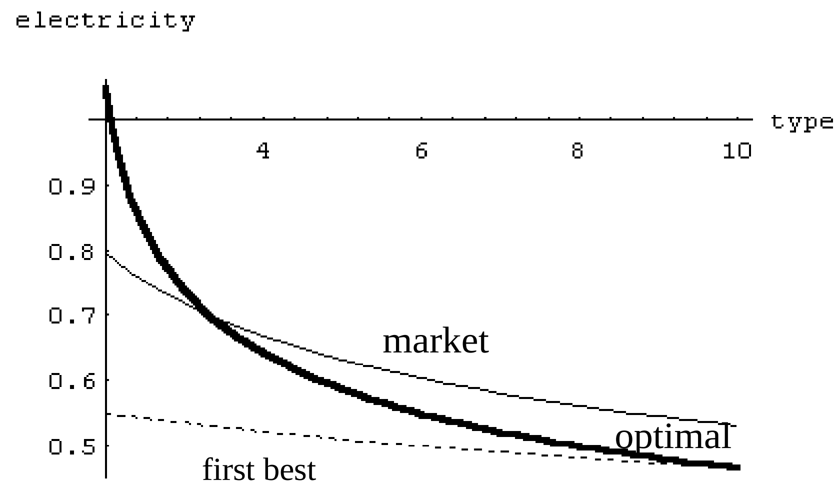
IC constraint

$$U^a(t \mid t) \ge U^a(\hat{t} \mid t) := tw(\eta(\hat{t})) - K(\eta(\hat{t})) + \tau(\hat{t})$$

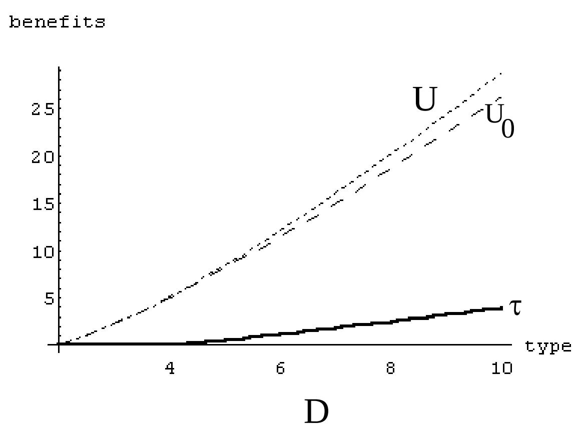
Optimal program

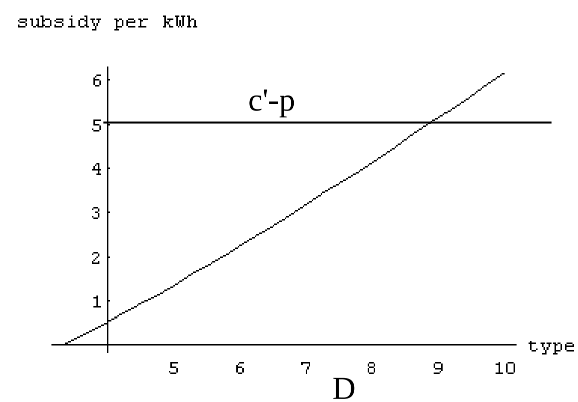


a: efficiency choices with & without incentives



b: resulting electricity demand





=> Subsidize efficient (i.e. rich) instead of inefficient (poor) households

Optimal Conservation Incentives general properties

- The private information of the crucial decision makers – the consumer/firm – must be taken into account.
- As a consequence, subsidies should focus on efficient and large consumers, inefficient while small consumers should be bypassed. Needless to say, this is contrary to political intentions.
- **Commitment problems** on the supply and on the demand side (e.g., recently Spain & PV), but I venture similar conjectures, definitely for electric cars but also for e.g., for passive heated homes.

Utility programs

- **Puzzle** Conservation programs have a small margin (*c*'- *p*). Given the above addressed consumer reactions utility conservation can be hardly profitable. Yet billions of $s are spent.
- Regulatory constraints - rate of return regulation combined with incentives – can render it profitable, but the utilities have an incentive to invest *in hypothetical conservation* but try to minimize (through program design, the choice of consumer groups) actual conservation
  Wirl 1995, *Journal of Regulatory Economics*: *Consider two programs A and B that have identical costs and engineering efficiency improvements but different (ex post) impacts on the savings. Then, the utility prefers the program with less factual conservation. Similarly, consider two programs that are identical from the point of conservation (hypothetical and factual) but have different costs. Then the utility will engage, if at all, in the program with the higher costs.*
- **Explanation**: Common interest between the utility and the regulatory commission to report a success.
- But why did the experts overlook, or down play these problems?
  Murrell (1995), 'this dual role of activist and academic commentator is dangerous given the strong personal, political, professional, and possibly financial stakes involved'

Concluding remarks

- Efficiency improvements are crucial, but cannot be the (only) magic bullet solving resource and environmental problems.
- The claim of irrational consumers is dubious, paternalistic at best, and inefficient in many instances (e.g., SL-18 in WC).
- This holds a fortiori for utility or government run programs (past and future = white certificates in EU).
- Commitment problem – serious but mostly ignored.
- US experience was very disappointing (mildly put).
- Given this inefficiency and past failures,
  why was and is this issue so high on the agenda?
  ‘Das Gegenteil von gut ist gut gemeint’
  Frank Knight (1950), "*Error and ignorance often are not due to low mental capacity but to 'prejudice', which can blind men even to the obvious*"
  Buchanan (1995, p148), "Political choice may, in particular, be made on the basis of romantic projections that cannot be generated by behavorial reality."

Thank You for Your attention

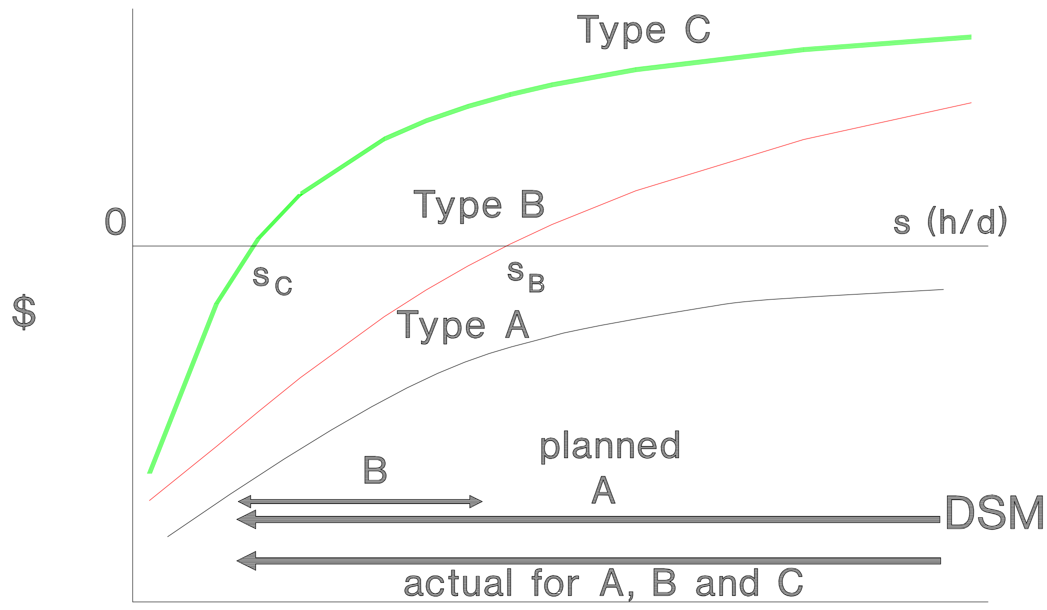
Morale Hazard

Implications of programs (= subsidies) on conservation

Example: Utility replaces 75 W by SL-18 bulbs for heavy use bulbs.
Three consumer types, B = efficient

Idea: Again subsidize inefficient households, types: A and C.

Optimal ? No since the program crowds out the own efforts, here of B and to some extent of C.



Least cost planning – continued perfect information

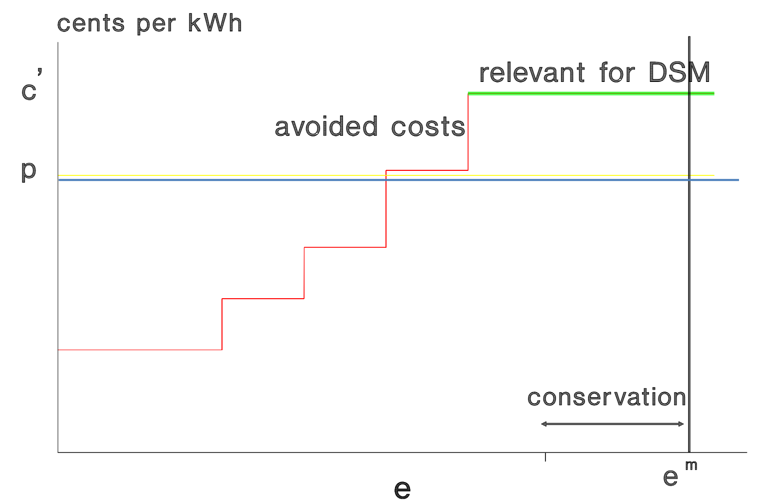
$$V := R(p - c(E(\eta_0 + \Delta\eta)))E(\eta_0 + \Delta\eta) - Z(\Delta\eta),$$

$R \geq D$, *payback gap*, Z = program costs for inducing efficiency upgrade $\Delta\eta$.

(annual) costs for a negawatt = $-\rho Z'/E_\eta$

=

the loss delivering this kWh = (*c*' - *p*)



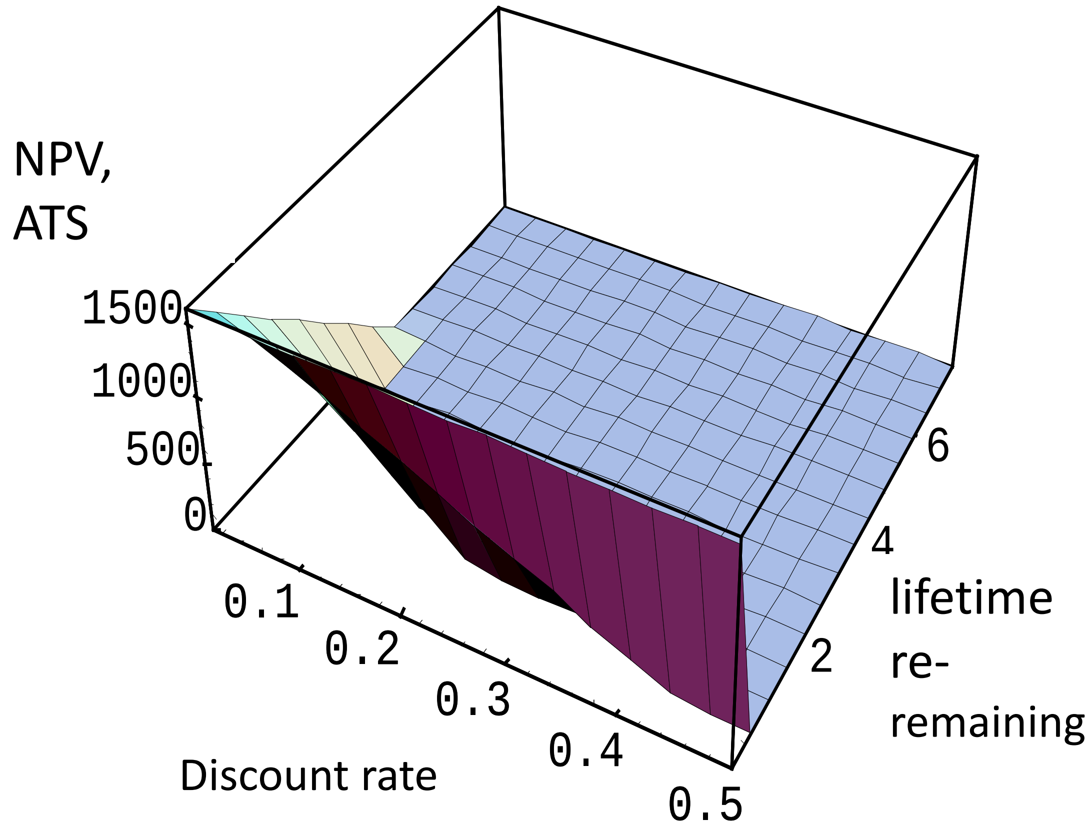
in particular $p \geq c' \Rightarrow$ *no conservation irrespective how cheap conservation may be*. Hence Lovins' criterion is wrong for a utility

Explanations? Account for the loss in revenues due to conservation (ignored by Lovins)

Adverse Selection (subsidies)

Incentives – subsidies
Example SAFE:
Refrigerator
annual saving = 200 ATS/a,
Costs = 8000 ATS, L = 15a,
Subsidy (20%) = 1600 S.

Private Information:
remaining life time
subjective discount rate



The appliance turn in program, Salisbury (Austria) 1989, washing machines.

Engineering data: (no rebound)

223 kWh	annual average electricity consumption of the average replaced washing machine.
166 kWh	the average new appliance, i.e., a reduction of 57 kWh, or 26 %.
130 kWh	the most efficient washing machine, a reduction of 93 kWh, 42%.

Program details and data

The program provided subsidies of 20% of the sales price for replacing old appliances (washing machine, refrigerator, freezer, dishwasher, electric stove).[a]

Theoretical, engineering conservation: per participating household	≥ 57 kWh
Actually measured, average conservation: i.e., no conservation but an increase!	-76 kWh,
Average increase of other households:	150 kWh
Hypothetical conservation:	74 kWh

[a]The program in addition offered a bounty (for two years and up to 5 % of the electricity bill) for reducing electricity consumption. The effect of this bounty is neglected in the following.

Learning abatement costs: On the dynamics of optimal regulation of experience goods

Beat Hintermann and Andreas Lange

University of Basel University of Hamburg

Motivation

- New technologies are experience goods
- Unknown ex ante:
  - quality
  - total costs/utility
- many situations where a new technology becomes available that is characterized by uncertainty about its associated costs, benefits and/or utility, and by a reduction of external damage

Framework

- 2 alternatives: Status quo (A) and new technology (B)
  - A dirty but cheap
  - B clean but expensive
- Consumers learn full costs/utility when trying B once
  - personal experience necessary
  - decision reversible
- Related literature on dynamic pricing of experience goods
  - Shapiro (1983), Cremer (1984), Farrell (1986), Milgrom & Roberts (1986), Tirole (1988)
  - Bergemann & Välimäki (2006)
    - Monopolistic pricing of experience goods
    - Non-monotonic pricing for "niche" markets

Overview

This paper:

1. two different regulatory regimes:
   (i) first-best case: regulate number of inexperienced consumers that are exposed to the new technology for the first time, and the set of experienced consumers who should continue using the technology
   (ii) regulator relies on subsidies/taxes only, i.e. one instrument to impact behavior of the experienced consumers as well as the inexperienced consumers' learning decision
2. first-best implemented by complementing an increasing tax
3. biases in discount rates require complementing (an increasing) tax with a subsidy for first-time users
4. rationale for subsidies based on consumer learning

Model

- total costs from B: $\theta_i = \Delta_i + \delta_i$
- uncertainty: $g(\Delta)$, $f(\delta)$;   cdf: $G(\Delta)$, $F(\delta)$
- known cost of marginal informed consumer at t: Δ_t
- cost threshold of participation for informed consumers: θ_t
- usage rate of B

$$\Omega_t = \int_{-\infty}^{\Delta_t} F(\theta_t - \Delta) dG(\Delta) + G(\Delta_{t+1}) - G(\Delta_t)$$

- environmental damages from A: $D[1 - \Omega_t]$; $D' > 0, D'' > 0$
- costs from B: $C[\Omega_t]$; $C' > 0, C'' > 0$

Social planner

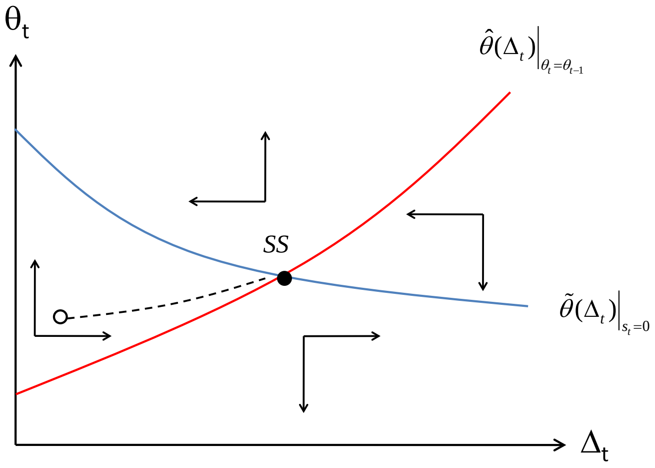
$$\min_{\theta_t, s_t, k_t} \quad \sum_{t=0}^{\infty} e^{-rt} \Bigg(\int_{-\infty}^{\Delta_t} \int_{-\infty}^{\theta_t - \Delta} (\Delta + \delta) dF(\delta) dG(\Delta) + \int_{\Delta_t}^{\Delta_t + s_t} \Delta dG(\Delta) + D[1 - \Omega_t] + C[\Omega_t] + A[k_t] \Bigg)$$

$$s.t. \quad \Delta_t + s_t = \Delta_{t+1}$$

$$\theta_t \geq 0, \; s_t \geq 0, \Delta_0 \geq 0$$

$$\sum k_t \geq \Omega_t$$

First-best



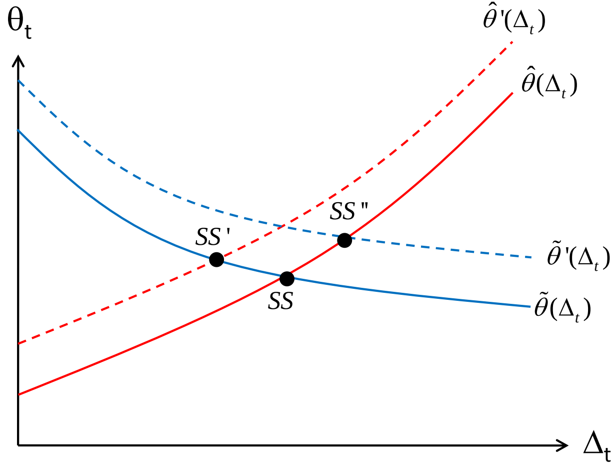
θ_t
$\hat{\theta}(\Delta_t)\big|_{\theta_t=\theta_{t-1}}$
SS
$\tilde{\theta}(\Delta_t)\big|_{s_t=0}$
Δ_t

Result – First best

Proposition 1 *In the first-best transition path into the steady state, consumers with the smallest expected costs experience the new technology first, such that the marginal costs of participation increase over time.*

- surprising (?) at first glance: One might expect that as consumers learn, more people use the new technology such that net marginal damages decrease over time.
- two effects overlap:
  - if there is no binding constraint on the capacity, it is optimal for consumers to learn in the beginning, which leads to an initially high but rapidly declining learning rate
  - The decline in s_t more than compensates the increase in Δ_t over time, such that we actually observe a net decline in usage Ω_t, and thus an increase in net marginal damages

Comparative statics I



Comparative statics II

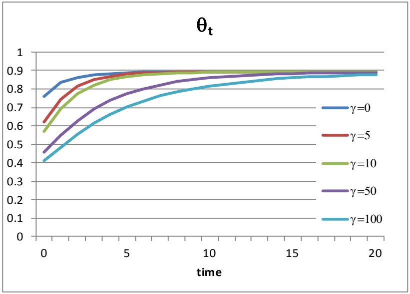


Fig. 3a: Cost limit

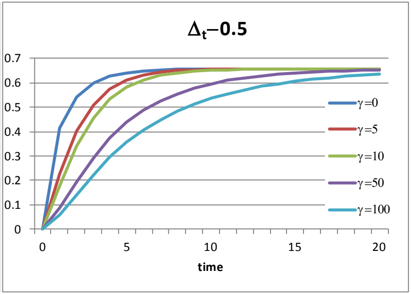


Fig. 3b: State of learning

Comparative statics III

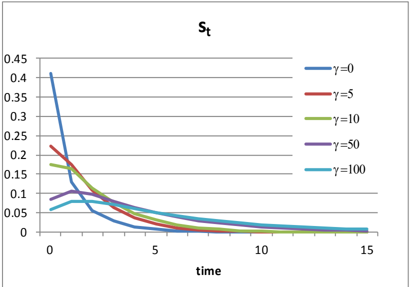


Fig. 3c: Rate of learning

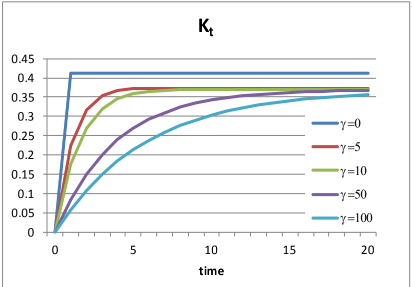


Fig. 3d: Total capacity

Comparative statics IV

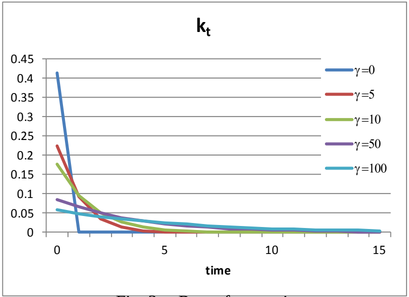


Fig. 3e: Rate of expansion

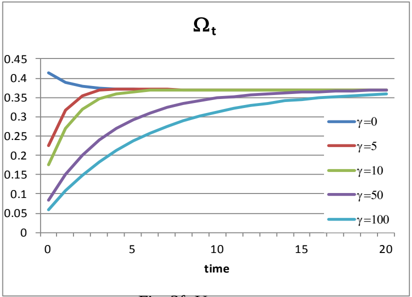


Fig. 3f: Usage rate

Result – Policy

Proposition 2 *The first-best transition path can be implemented using a usage tax τ_t for the dirty alternative in combination with a subsidy for first-time users σ_t.*

Proposition 3 *If social and private discount rates coincide, the first-best solution can be decentralized by taxing the dirty alternative, whereas no subsidy for first-time users is necessary. If the private discount rate exceeds the social discount rate, a subsidy for first-time users is necessary to implement the first-best solution. This (discounted) subsidy is decreasing over time, i.e. $\sigma_{t-1} > \sigma_t \exp(-r_p)$.*

Result – Policy

- with larger private discount, individuals do not have sufficient incentives to learn
- subsidizing first-time users is optimal. The (discounted) subsidy must decrease over time.

$\Rightarrow$ a reason for why regulators may adjust their policies in a dynamic setting, specifically temporarily subsidize trying a new alternative

Result – Decentralization with one instrument

Proposition 4 *If the private discount rate r_p exceeds the social discount rate r , the second best policy involves a taxation path that is first increasing, but will decrease at one point in time before being constant.*

- learning only along increasing portion of path
- for $r_p > r$, we have that $\theta_S^{SS} < \theta_P^{SS}$ and $\Delta_S^{SS} > \Delta_P^{SS}$

$\Rightarrow$ any increasing tax path can maximally end up in $(\theta_P^{SS}, \Delta_P^{SS})$

$\Rightarrow$ with a temporarily higher tax rate, one induces additional consumers to learn

$\Rightarrow$ with more informed consumers (and more using the clean alternative), the tax rate can be lowered

$\Rightarrow$ Optimal second-best path for θ_t non-monotonic!

Discussion

- demonstrated how regulation should incorporate dynamic features that initiate from "learning-by-trying"
- regulation needs to simultaneously account for two dimensions:
  - experienced consumers will use the new technology (public transport) if their private opportunity costs are outweighed by the external damages of the private transport alternative.
  - policy in its introductory phase needs to control the optimal number of new consumers.
- Introductory subsidies justified from consumer perspective if consumers not fully rational
  - $r_p > r$
  - biased expectations
- If σ_t feasible: decreasing over time; θ_t monotonically increasing
- If not: non-monotonic downward adjustment of θ_t

Transitions towards energy efficient lighting and rebound effects

Joachim Schleich

Fraunhofer ISI, Germany / Grenoble Ecole de Management, France

13 March 2014

Workshop

The Energy Efficiency Gap: Reasons and Implications

ZEW Mannheim

Collaborators:
Brad Mills, Virginia Tech

Elisabeth Dütschke, Fraunhofer ISI

Fraunhofer ISI

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Introduction

- Adopting energy-efficient technologies may lead to smaller energy savings than engineering-economic analyses suggest
- Improved energy efficiency lowers marginal (and possibly avarage) costs of energy services
- Demand for energy services increases
- Rebound effects
  - Direct
  - Indirect
  - Macroeconomic

Introduction

- Empirical findings for direct rebound effect:
  - Heating : 2% to 60%
  - Mobility : 5% to > 80%
  - Lighting : 5% to 12%

Objective

- Quantify direct rebound effect for residential lighting
  - Accounting for
    - Change in burntime
    - Change in luminosity
    - Type of bulb switch
- Analyse (jointly) determinants of
  - Rebound
  - Bulb choice

Methodology

- BMBF-sponsored research project: Social dimension of rebound (ZEW (coordinator), Fraunhofer ISI, RWI, University of Stuttgart)
- Representative, computer-based survey of 6,409 German households (GfK Panel) in May/June 2012
- Questions on most recent bulb replacement
  - Type , Wattage (5 wattage categories per type)
  - Room ? Main bulb ?
  - Δ burn time (subjective) ? (0, <15, 15 to 30, 30 to 60, >60 min)
- Opt out (“don’t remember”), visual interface, photographs of different bulb types shown

Rebound calculation

Demand for useful work to provide *lighting services* may be expressed as

$$(1) \quad S = \Phi t$$

where Φ stands for luminosity (in lm), and t reflects burn time (in h).

Employ the ***efficiency elasticity of useful work*** as a direct measure of the rebound effect:

$$(2) \quad \eta_{S,\varepsilon} = \frac{\partial S}{\partial \varepsilon}\frac{\varepsilon}{S}$$

ε reflects efficiency (i.e. efficacy measured in lm/W)

Rebound calculation
– a more intuitive expression

Equation (2) may for discrete changes be expressed as:

$$1 - \frac{observed\ electricity\ savings}{theoretical\ electricity\ savings}$$

Rebound calculation

Decompose *efficiency elasticity of useful energy* into the elasticity of luminosity (luminosity rebound) and the elasticity of burn time (burn time rebound):

$$(3) \quad \eta_{S,\varepsilon} = \frac{\partial \Phi}{\partial \varepsilon}\frac{\varepsilon}{\Phi} + \frac{\partial t}{\partial \varepsilon}\frac{\varepsilon}{t} = \eta_{\Phi,\varepsilon} + \eta_{t,\varepsilon}$$

.

Note that energy demand is

$$E = \Phi t \varepsilon^{-1}$$

Thus, *efficiency elasticity of energy demand* is

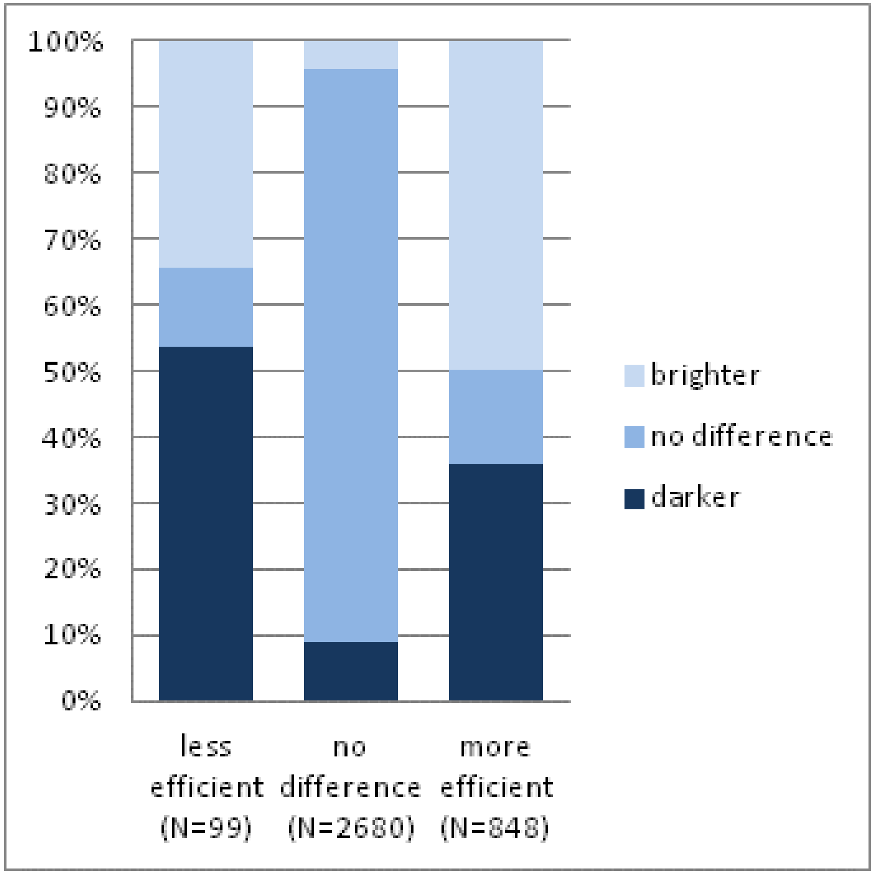
$$(4) \quad \eta_{E,\varepsilon} = \eta_{\Phi,\varepsilon} + \eta_{t,\varepsilon} - 1$$

Results: Initial and replacement bulb by type

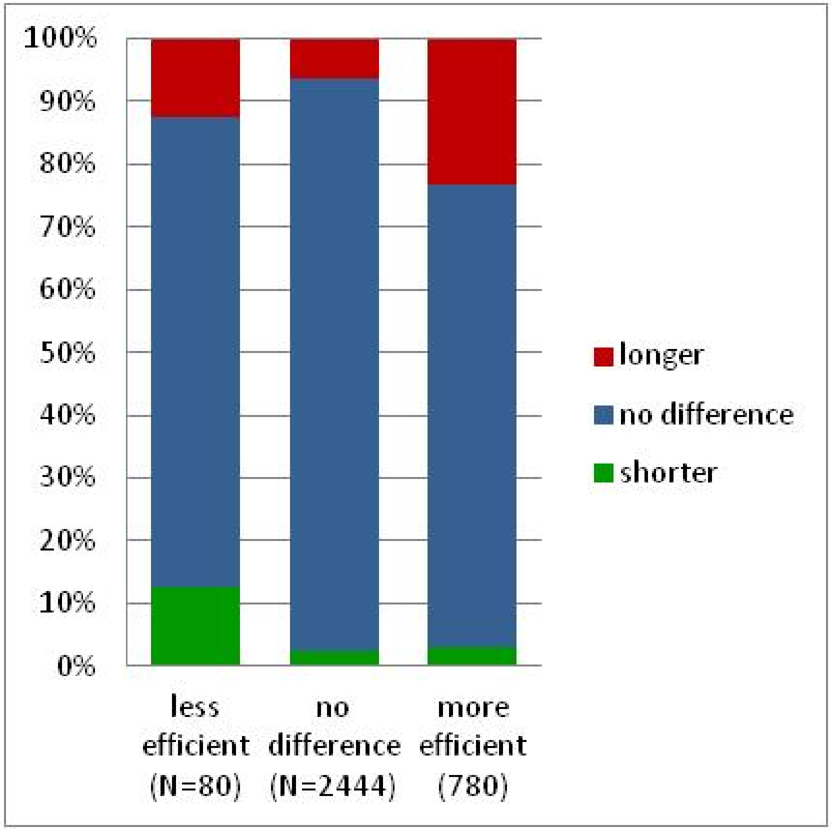
	Replacement bulb type				
Initial bulb type	IL	Halogen	CFL	LED	*Sum*
IL	984	56	544	94	*1,678*
Halogen	94	728	41	113	*976*
CFL	68	18	1,026	75	*1,187*
LED	0	8	6	98	*112*
Sum	*1,146*	*810*	*1,617*	*380*	*3,953*

For initial ILs, 80% (544 of 638) of the efficiency-improving switches were towards CFLs
For initial halogen bulbs most efficiency-improving switches were towards LEDs (73%).
For efficiency-improving switches, the new bulb is – on average - 4.4 times more efficient than the initial bulb

Results: Luminosity



Results: Burn time



Summary on quantification

- On average, more efficient replacement bulbs
  - are 23% brighter (main bulb in dining/living room - modal bulb: 10%)
  - burn about 6.5 minutes per day longer (modal bulb: 9 minutes, ca. 5%)
- Direct rebound effect for the average bulb: 6.3% (modal: 2.6%)
  - Luminosity: ca. 60% (modal bulb: 40%)
- Findings differ by types of initial and replacement bulbs
  - E.g.: switch from IL to LED is associated with a larger luminosity and larger total rebound than a switch from Halogen to LED.
- About a third of the bulb switches entail a negative rebound

Analysing determinants of transition

- Bulb choice
- Change in luminosity
- Account for possible self selection in bulb type choice , i.e. only observe luminosity change for chosen bulb
  - Estimate bulb choice and change in luminosity jointly
- “Co-Benefit”: - assess effectiveness of ban on ILs

Results – Choice Equation

Table 3: Multinomial Logit Relative Risk Ratio Estimates

	Full-Sample					
	IL to CFL			IL to LED		
	RRR	Std. Err.		RRR	Std. Err.	
time12	0.585	0.082	***	0.591	0.162	*
bantime	1.821	0.373	***	3.226	1.092	***
lamp	2.792	1.040	***	4.035	2.029	***
storage	0.183	0.023	***	0.033	0.011	***
main	1.415	0.202	***	1.736	0.512	*
bedrm	0.809	0.194		1.803	0.739	
kitcrm	0.910	0.186		1.492	0.539	
hallrm	0.808	0.147		1.117	0.376	
childrm	1.049	0.425		1.004	0.753	
bathrm	0.748	0.142		0.537	0.208	
otherrm	0.964	0.205		0.381	0.204	*
outdoor	1.150	0.417		1.625	0.981	
rent	1.045	0.141		0.748	0.192	
price	1.159	0.164		1.396	0.411	
quality	1.195	0.165		1.722	0.504	***
electuse	2.504	0.328	***	7.834	2.497	***
durable	1.275	0.166	*	1.825	0.514	**
environ	2.391	0.385	***	2.969	0.971	***
dimable	0.768	0.212		2.303	1.151	*
middle	1.080	0.170		0.963	0.279	
high	1.088	0.186		0.756	0.245	
female	0.909	0.113		0.556	0.139	**
young	0.598	0.160	*	0.380	0.212	*
old	0.749	0.126	*	1.124	0.355	
twopers	1.033	0.159		1.008	0.308	
twoplus	1.124	0.195		1.868	0.620	*
Log-likelihood	-1165.846					
N	1,714					

Note: ***, **, and * indicate statistical significance at p=0.01, p=0.05, and p=0.1 levels in two-tailed t-tests, respectively.

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Results – Luminosity Equation

	IL to IL Coef.		IL to CFL Coef.		IL to LED Coef.	
lamp	0.183		-0.151		1.121	*
storage	-0.147	***	-0.232		-1.094	
main	0.055	**	0.026		0.243	
bedrm	0.006		0.011		-0.052	
kitcrm	0.015		-0.019		-0.018	
hallrm	0.004		0.115		0.456	
childrm	0.067		-0.054		0.875	
bathrm	0.017		0.134		-0.810	*
otherrm	0.010		-0.107		-0.574	
outdoor	0.001		-0.221		0.022	
price	0.010		-0.013		-0.106	
quality	-0.001		-0.166	**	-0.273	
electuse	0.072	**	-0.034		0.435	
environ	0.071	**	-0.019		-0.044	
middle	0.005		-0.111		0.338	
high	-0.012		-0.196	**	0.159	
female	0.030	*	0.168	**	-0.113	
young	-0.059	*	0.328		-0.954	
old	-0.045	*	-0.172	**	0.269	
twopers	-0.004		0.093		0.064	
twoplus	-0.009		0.135		0.587	
m*i*	0.300	***	-0.270		-1.298	**
constant	1.152	***	1.183	***	-1.251	
Sigma2	0.071	***	0.769	***	7.331	
F-Test	2.170	***	1.620	**	1.150	
Adj. R^2	0.025		0.024		0.048	
N	996		553		111	

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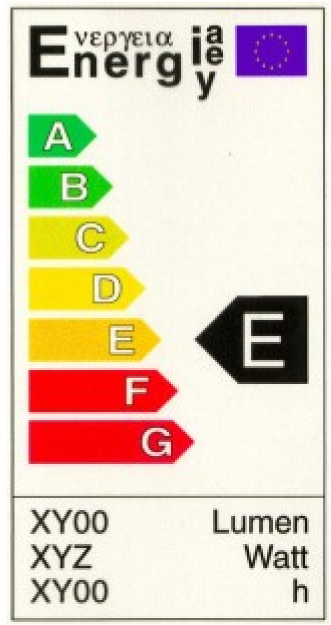
Summing up

- Overall direct rebound in lighting appears to be small, but substantial share due to higher luminosity
- Nature of calculated rebound (here: increase in luminosity) not clear
  - Welfare improving (unsatiated needs)?
  - Rational response to technology performance (quality of light, performance, ….)
  - Result of lack of information / bounded rationality (combined w/ risk aversion)

EU energy label for light bulbs



Summing up

- Overall direct rebound in lighting appears to be small, but substantial share due to higher luminosity
- Nature of calculated rebound (here: increase in luminosity) not clear
  - Welfare improving (unsatiated needs)?
  - Rational response to technology performance (quality of light, performance, ….)
  - Result of lack of information / bounded rationality (combined w/ risk aversion)
- Econometric models explain bulb choice “better” than luminosity rebound
  - Luminosity rebound smaller if level of education high
  - Unexplained heterogeneity
- Bulb phase out effective, but likely to involve rebound

Thank you!

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Discussion

- Rebound likely to be larger for other applications (transport, in particular)
- Empirical findings vary substantially
- Only few studies on rebound in industry exist
- Methodological challenges
  - Most empirical work identifies direct rebound effect via estimated own-price elasticity (restrictive assumptions?)
  - Potential endogeneity
- Policy making
  - Important to distinguish between rational responses (“true” rebound and response to technology performance) and behavioral factors

Presentation is based on

- Schleich, J., Mills, B., and Dütschke, E. (2014). A Brighter Future? Quantifying the Rebound Effect in Energy Efficient Lighting. Fraunhofer ISI Working Paper Sustainability & Innovation 3/2014.
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Other literature includes

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- Turner, K., 2013. Rebound effects from increased energy efficiency: A time to pause and reflect. Energy Journal 34, 25-42.
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Energy Efficiency and Household Behavior: The Rebound Effect in the Residential Sector

Erdal Aydin & Dirk Brounen & Nils Kok

March 9, 2014

Residential Energy Consumption

- Residential sector: 40% of total energy consumption in EU
- Introduction of Energy Efficiency Policies
  - Building codes
  - Subsidies for energy efficiency improvements
  - Financial instruments
- Policy expectation: an increase in efficiency leads to an equal amount of energy saving

Rebound effect

- Improved efficiency$\rightarrow$ reduced cost $\rightarrow$ increased demand

  This demand increase is referred to as the rebound effect, as it offsets the reduction in energy demand that results from an increase in efficiency. Example: Car travel

- Formal definition: Elasticity of the demand for a particular energy service with respect to efficiency

Research question

- What is the magnitude of the rebound effect for residential heating?

Literature: Rebound Effect in residential heating

- Estimates are ranging from 15% to %60
- Methodological problems
  - Use of "Price elasticity" instead of "Efficiency elasticity"
  - Incomplete measures of activity change (thermostat setting?)
  - Small sample size
  - Sample selection bias
  - Measurement error in engineering predictions
  - Heterogeneity

Panel Data

- Number of dwellings (households): 560,000

- Energy Labels (Issued in 2011 and 2012)
- Actual gas consumption (2008-2011)
- Household characteristics (2008-2011)
- Dwelling characteristics

Variables

- Annual Actual Gas Consumption (CBS)
- Predicted Gas Consumption (AgentschapNL)

Control Variables:

- Dwelling Characteristics (AgentschapNL)
  - House type/size, Construction year, Province
- Household Characteristics (CBS)
  - Size, Age, Gender, Income, Tenure, Employment status
- Dwellings without label (NVM)
  - Number of dwellings (households): 120,000

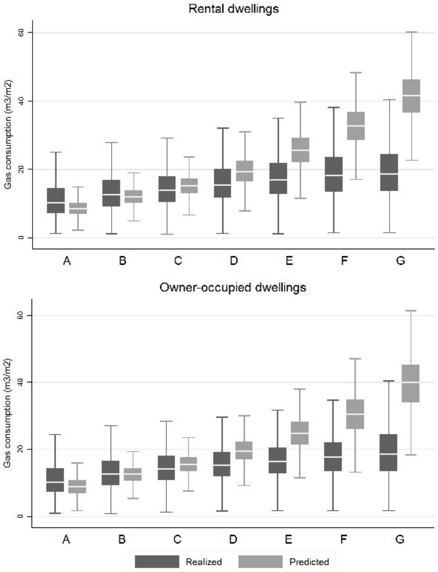
Descriptive Statistics-1

Number of Observations	Rental (With Label) *519,512*		Owner-Occupied (With Label) *43,498*		Owner-Occupied (Without Label) *122,119*	
Variables	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
Actual Gas Consumption (m^3)	1,245	(526)	1,588	(665)	1,573	(632)
Predicted Gas Consumption (m^3)	1,492	(624)	1,887	(759)		
Actual Gas Consumption (m^3/m^2)	15.7	(7.1)	15.3	(6.2)		
Predicted Gas Consumption (m^3/m^2)	18.7	(8.1)	18.2	(7.1)		
Size (m^2)	82.2	(21.6)	106.7	(34.7)		
Label:						
Label-A (EI$<$1.06)	0.02		0.03			
Label-B (1.05$<$EI$<$1.31)	0.16		0.17			
Label-C (1.30$<$EI$<$1.61)	0.33		0.32			
Label-D (1.60$<$EI$<$2.01)	0.25		0.24			
Label-E (2.00$<$EI$<$2.41)	0.14		0.14			
Label-F (2.40$<$EI$<$2.91)	0.07		0.08			
Label-G (2.90$<$EI)	0.03		0.02			
Dwelling Type:						
Apartment	0.49		0.27		0.21	
Semi-detached	0.32		0.21		0.32	
Corner	0.19		0.32		0.32	
Detached	0.00		0.20		0.15	

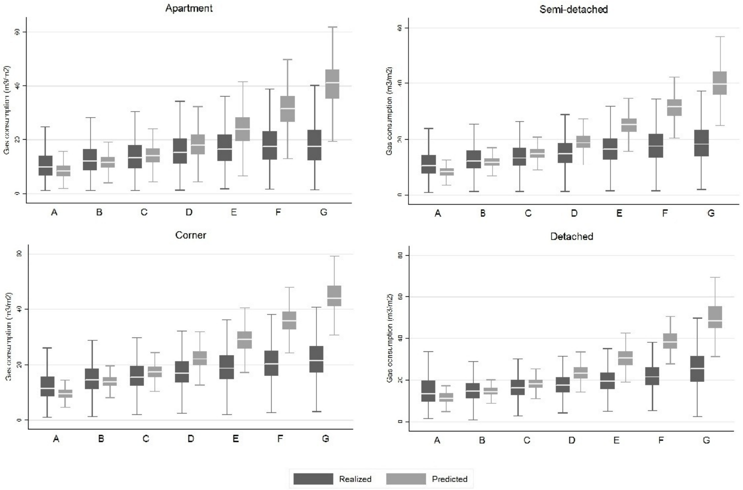
Descriptive Statistics-2

Number of Observations	Rental (With Label) *519,512*		Owner-Occupied (With Label) *43,498*		Owner-Occupied (Without Label) *122,119*	
Variables	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
Construction Period:						
1900-1929	0.07		0.10		0.12	
1930-1944	0.03		0.08		0.09	
1945-1959	0.17		0.14		0.08	
1960-1969	0.20		0.19		0.15	
1970-1979	0.19		0.25		0.17	
1980-1989	0.20		0.12		0.14	
1990-1999	0.11		0.09		0.16	
>2000	0.03		0.03		0.09	
Household Characteristics:						
Number of Household Members	1.91	(1.12)	2.36	(1.21)	2.28	(1.21)
Number of Elderly (Age>64)	0.46	(0.68)	0.29	(0.62)	0.31	(0.61)
Number of Children (<18)	0.34	(0.78)	0.50	(0.89)	0.53	(0.91)
Number of Females in Household	1.01	(0.74)	1.16	(0.77)	1.13	(0.79)
Number of Working Household Members	0.84	(0.94)	1.48	(0.99)	1.35	(0.96)
Household Annual Net Income (1000 Euro)	23.8	(11.5)	36.9	(17.1)	37.3	(26.2)
Household Wealth (1000 Euro)	22.6	(91.6)	177.8	(393.8)	191.3	(531.5)
Share of Households Receiving Rent Subsidy	0.41					

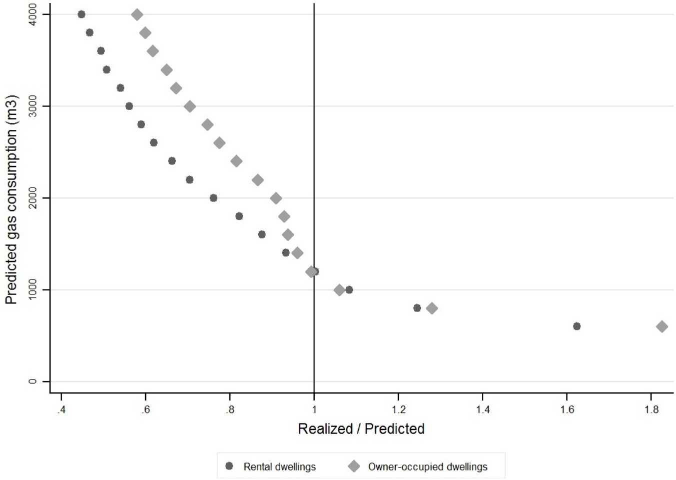
Predicted versus Actual Gas consumption



Predicted versus Actual Gas consumption



Predicted versus Actual Gas consumption



Rebound Effect

$$\tau_G = \frac{\partial ln(H)}{\partial ln(\mu_H)} \tag{1}$$

$$\mu_H = \frac{H_r}{G^*}, H = H_r \frac{G^a}{G^*} \tag{2}$$

$$\tau_H = 1 - \frac{\partial ln(G^a)}{\partial ln(G^*)} \tag{3}$$

- τ_G : Rebound effect
- H : Heating demand (combination of temperature, heating duration, and share of heated area)
- μ_H : Efficiency of the dwelling
- H_r : Reference heating level
- G^* : Predicted gas consumption for reference heating level
- G^a : Actual gas consumption

Empirical Model

$$ln(G^a_{it}) = \beta_0 + \beta_1 ln(G^p_{it}) + \sum_{j=2}^{j} \beta_j Z_{jit} + \alpha_i + \varepsilon_{it} \qquad (4)$$

$$\tau_G = 1 - \frac{\partial ln(G^a)}{\partial ln(G^p)} = 1 - \beta_1 \qquad (5)$$

- G^a: Log of Actual Gas Consumption
- G^p: Log of Predicted Gas Consumption
- Z : Control variables
- t : Time dummies
- α : Household specific effects

Pooled OLS Estimations

	(1) Rental	(2) Owner-Occupied	(3) Rental	(4) Owner-Occupied
Log (Predicted Gas Consumption)	0.485***	0.589***	0.441***	0.528***
	[0.001]	[0.003]	[0.001]	[0.003]
Number of Household Members			0.118***	0.132***
			[0.001]	[0.005]
Number of Household Members^2			-0.012***	-0.014***
			[0.000]	[0.001]
Number of Children (<18)			-0.009***	0.001
			[0.001]	[0.003]
Number of Elderly (Age>64)			0.031***	0.049***
			[0.001]	[0.003]
Number of Female			0.037***	0.016***
			[0.001]	[0.003]
All Household Members Are Working (1=yes)			-0.060***	-0.042***
			[0.001]	[0.003]
Log (Household Income)			0.054***	0.075***
			[0.001]	[0.003]
Receiving Rent Subsidy (1=yes)			-0.032***	
			[0.001]	
Province Dummy	Yes	Yes	Yes	Yes
Year Dummy	Yes	Yes	Yes	Yes
Constant	3.725***	3.038***	3.295***	2.481***
	[0.006]	[0.026]	[0.012]	[0.039]
R^2	0.210	0.361	0.255	0.402
Number of observations	1,664,113	87,282	1,664,113	87,282
Number of dwellings	519,512	43,498	519,512	43,498

Measurement Error in Engineering Predictions

- Random measurement error in "Predicted Gas Use"

$$G^p = G^* e \tag{6}$$

- Instrument for "Predicted Gas Use": Construction year of the dwelling (Dummy variable)

Pooled OLS-IV Estimations

	(1) Rental	(2) Owner-Occupied
Log (Predicted Gas Consumption)	0.587***	0.733***
	[0.001]	[0.007]
R^2	0.239	0.375
R^2 (First stage regression)	0.225	0.256
Number of observations	1,664,113	87,282
Number of dwellings	519,512	43,498

Endogeneity

Problems with OLS

- Unobserved household characteristics that affect both the actual gas consumption and thermal quality of the dwelling
- energy-efficient households sort into energy-efficient dwellings

Control for household-specific effects

- Moving households: The address change generates a variation in theoretical gas consumption due to the change of the characteristics of the dwelling in which the household resides

Random&Fixed-Effects (IV) Estimations

	Random-Effects Model		Fixed-Effects Model	
	(1) Rental	(2) Owner-occupied	(3) Rental	(4) Owner-occupied
Log (Predicted Gas Consumption)	0.582***	0.722***	0.584***	0.663***
	[0.002]	[0.009]	[0.011]	[0.051]
R^2	0.209	0.355	0.165	0.243
R^2 (within)	0.032	0.017	0.024	0.021
R^2 (between)	0.222	0.357	0.176	0.249
Number of observations	1,664,113	87,282	994,804	44,876
Number of households	519,512	43,498	351,462	21,595

Heterogeneity: Different Wealth and Income Cohorts

Panel A: Wealth Cohorts (Owners)

	(1) 0-20%	(2) 20-40%	(3) 40-60%	(4) 60-80%	(5) 80-100%
Log (Predicted Gas Consumption)	0.602*** [0.021]	0.676*** [0.021]	0.724*** [0.018]	0.811*** [0.017]	0.811*** [0.019]
R^2	0.300	0.330	0.352	0.335	0.339
Number of observations	11,342	11,342	11,342	11,342	11,342

Panel B: Income Cohorts (Tenants)

	(1) 0-20%	(2) 20-40%	(3) 40-60%	(4) 60-80%	(5) 80-100%
Log (Predicted Gas Consumption)	0.515*** [0.004]	0.597*** [0.003]	0.599*** [0.003]	0.625*** [0.003]	0.598*** [0.003]
R^2	0.169	0.213	0.245	0.243	0.243
Number of observations	332,299	332,225	332,275	332,284	332,305

Heterogeneity: Quantile Regression Estimates

Panel A: Sample of Owners

	10^{th}	25^{th}	50^{th}	75^{th}	90^{th}
Log (Predicted Gas Consumption)	0.922*** [0.003]	0.826*** [0.002]	0.750*** [0.002]	0.644*** [0.002]	0.492*** [0.002]

Panel B: Sample of Tenants

	10^{th}	25^{th}	50^{th}	75^{th}	90^{th}
Log (Predicted Gas Consumption)	0.699*** [0.003]	0.647*** [0.002]	0.599*** [0.002]	0.553*** [0.002]	0.494*** [0.002]

Conclusions

- Average rebound effect:
  - 27 percent for homeowners, and 41 percent for tenants
  - If the efficiency of an average dwelling is doubled, this will lead to a 59 percent energy reduction in rental dwellings and a 73 percent energy reduction in owner-occupied dwellings
- Heterogenous effects:
  - Rebound effect decreases as the wealth and income level increases
  - Rebound effect increases as the actual gas use intensity increases

Policy Implications

- Inaccurate estimations of the payback times for measures taken to improve the energy efficiency
- Achievability of the targets that have been set for primary energy as well as for reducing CO_2 emissions

Buildings and energy

Michael Hanemann

Xavier Labandeira

ZEW Workshop The Energy Efficiency Gap

Mannheim, Germany March 12-13, 2014

The question being posed

The question being posed is not:

Is there an energy efficiency gap?

Instead, the questions are:

If you wanted to reduce residential energy use, is this possible?

How could you do it?

The elusive demand function for energy

- To be sure, there is a huge literature in which economists have estimated residential demand curves for energy.
  - I myself have participated in such exercises.
- But, does there really exist a residential demand curve for energy?
- Or, equivalently: Are the estimated demand curves meaningful?
  - Do they reliably tell us what future demand will be a month from now, a year from now, or five years from now, either with or without some policy intervention?
- I am not sure that the answer is YES.
- I have the same doubt about commercial demand functions for energy
- And I have the same doubt about residential demand functions for water.

Why do I think the demand curve is problematic?

(1) For most residential users, their consumption of energy is invisible to them.

They have no way of knowing what quantity they are consuming at the time of consumption.

They have no idea what the price is, either, at the time of consumption.

(2) Their consumption of energy is mediated through the physical structure of the building they live in and the hardware in it.

Some of those things may not be under their control.

Even when they are controllable, those things won't be changed often or instantaneously.

(3) There is likely to be great heterogeneity in the houses, the people, and the end uses. The energy demand curve is an aggregation of disparate components.

Compare to other uses

- Household transportation
  - Rate of fuel consumption is visible – how often do you fill the car
- Industrial/commercial
  - Depending on the industry, decision makers may be highly aware of energy use.
    - E.g., fuel managers for trucking companies or airlines pay attention to achieving savings of 1-2% in fuel use – savings that are invisible to home owners

The question of policy tools

- A key question underlying policy:
  - Do we want to reduce energy use by moving along a given demand curve?
  - Or, do we want to reduce it by *shifting* the demand curve inwards?
- The conventional approach to policy focuses on the former – getting the price right (raising the price appropriately) so as to reduce demand.
- The strategy in California over the past 40 years has aimed more at shifting the demand curve inwards by non-price initiatives.
- The recent interest in “nudges” – for example, messaging electricity users on their use relative to that of others – aims at shifting the demand curve inwards.

The two issues converge

- How to shift the demand curve inwards

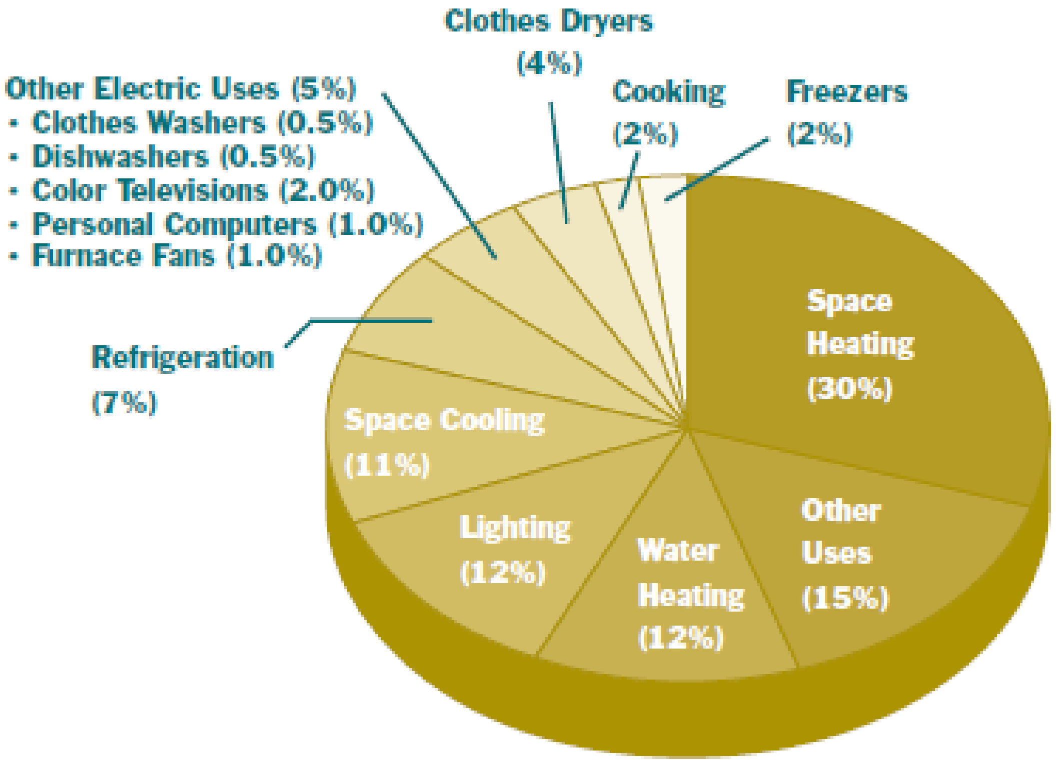
- How to conceptualize the demand curve and approach modeling it.

There is no “representative consumer” for residential energy use.

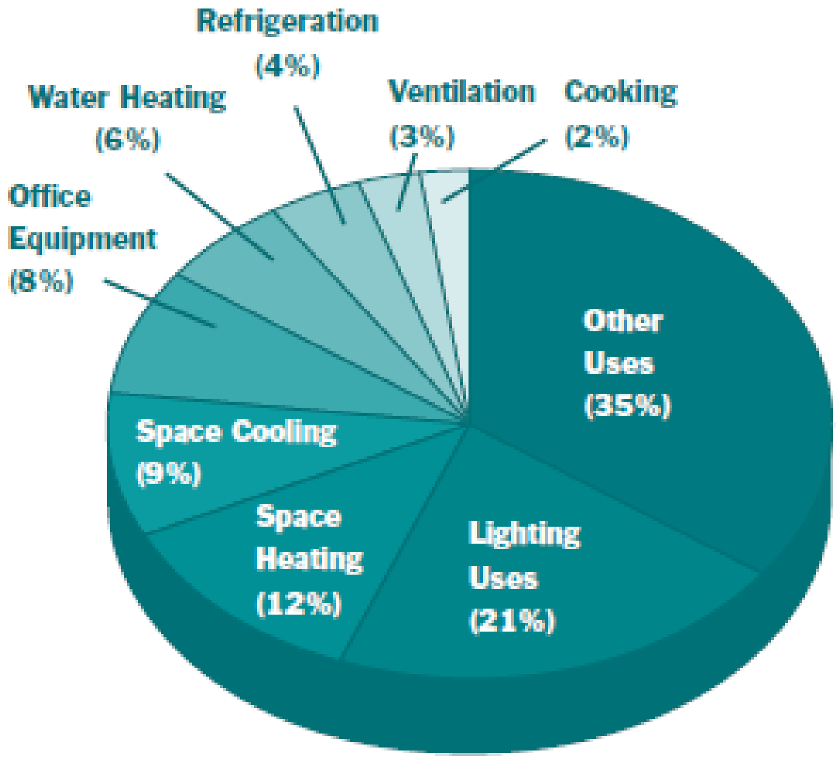
- You live in a house, which you own or rent.
- It was built by somebody else.
- What could you possibly change about the house?
- Why would you do this?
- In any case, how long will you live there?
- Houses come in many shapes, styles, vintages.
- Arguably, at any point in time the houses are far more heterogeneous than the people living in them

- You use energy for many purposes.
- Some of these you may be conscious of
  - E.g., air conditioning
- Some of these may be invisible to you
  - E.g., heating water
- Some of these uses you can readily modify
  - E.g., changing light bulbs
- Others are hard, perhaps impossible, for you to modify
  - E.g., home heating

Primary Energy Consumption in Residential and Commercial Buildings, 2002



Residential Buildings (Total Quads: 20.9)



Commercial Buildings (Total Quads: 17.4)

Note: Other energy uses in the residential sector includes small electric devices, heating elements, and motors; such appliances as swimming pool and hot tub heaters, outdoor grills, and outdoor lighting (natural gas); wood used for primary and secondary heating in wood stoves or fireplaces; and kerosene and coal.

Note: Other energy uses in commercial buildings include service station equipment, automated teller machines, telecommunications equipment, medical equipment, pumps, emergency electric generators, combined heat and power in commercial buildings, and manufacturing performed in commercial buildings.

Source: Energy Information Administration. 2004. Annual Energy Outlook 2004. DOE/EIA-0383, p. 139-142, tables A4 and A5. EIA, Washington, DC.

- The physical structure of the building has a huge effect on residential energy use

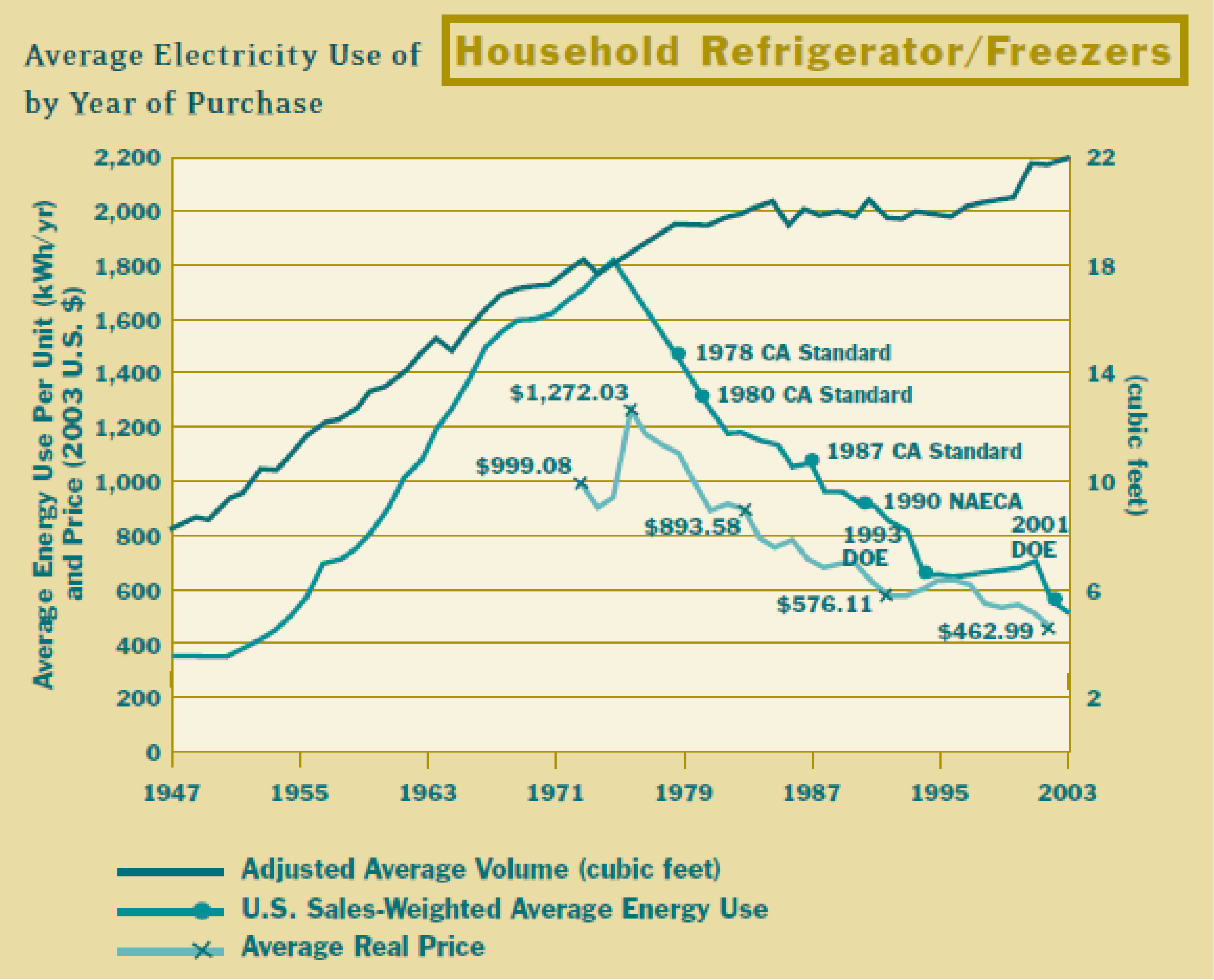
U.S. Residential Primary Energy

Consumption by Building Type, 2001

	% Total Units (2001)	% Total Owned (2001)	% Total Rented (2001)	% Total Btu (1997)
Single-family detached	59.0	52.1	6.9	73.4
Single-family attached	9.9	7.0	2.9	9.2
Building of 2–4 units	8.9	2.0	6.9	5.0
Building of 5 or more units	15.9	1.7	14.2	7.5
Mobile home	6.3	5.3	1.0	4.9
Total	100	68.0	32.0	100

Sources: Energy Information Administration. 2004. *2001 Residential Energy Consumption Survey: Housing Characteristics Tables*, EIA, Washington, DC. Table HC1-2a. Energy Information Administration. 2000, *1997 Residential Energy Consumption Survey*, EIA, Washington, DC. table 2.1.2, 1.2.6.

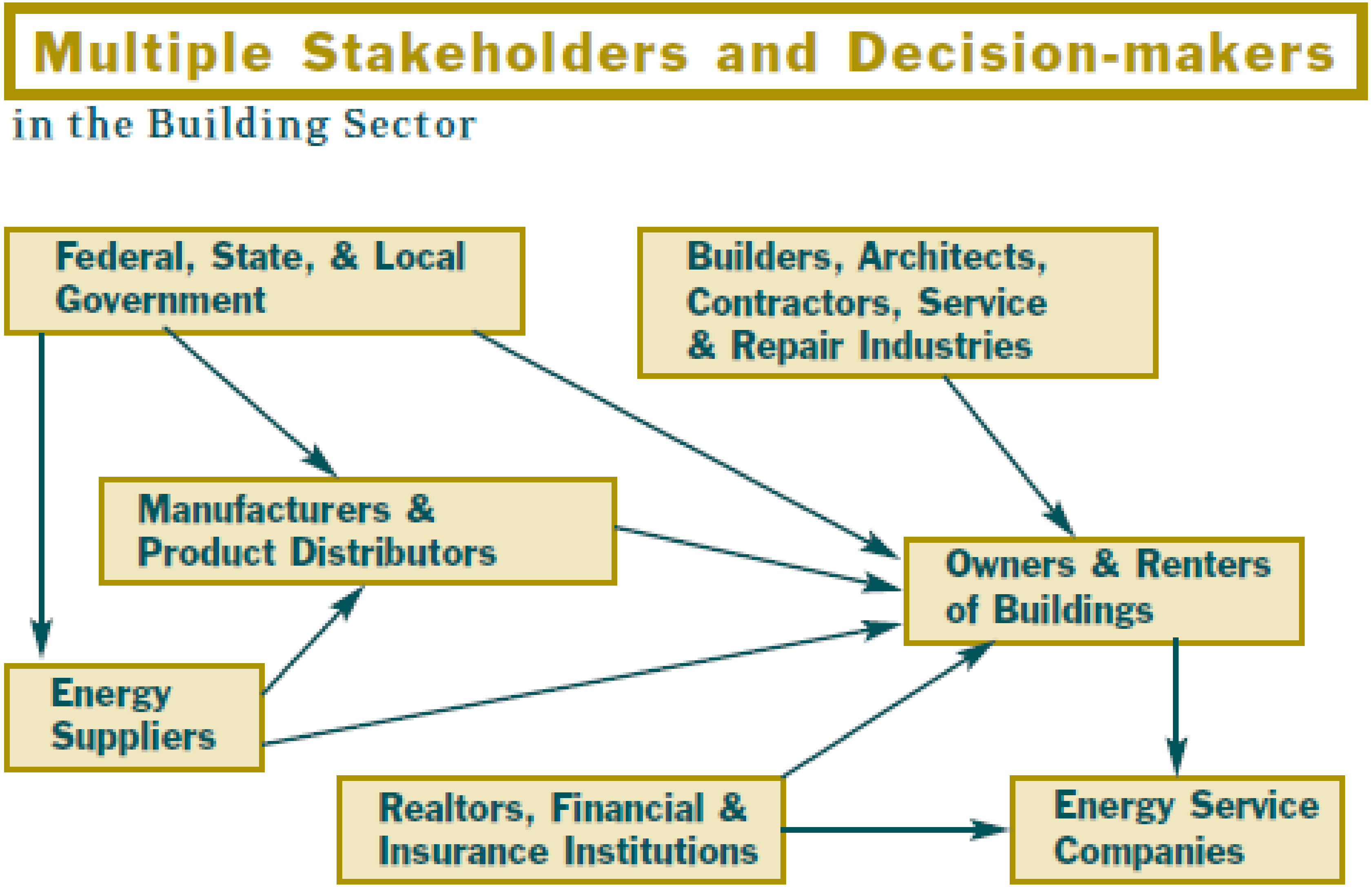
Many actors are involved in determining my residential energy use. My refrigerator, for example.



The locus of decision-making

- Who makes the decision?
  - What is the decision that they are making?
- Whose choice behavior do you want to influence?

Multiple actors



Who is the decision maker, continued

The building construction industry, especially homebuilding, is dominated by small and medium-sized firms. This is problematic because it means that a large number of firms and individuals need to be influenced to have a significant collective impact on energy efficiency. There were 1.65 million new home closings in the United States in 2002, and nearly 500,000 homebuilders operated that year. The five largest of these homebuilders accounted for less than 7 percent of new homes, while the top 100 accounted for just another 7 percent.[44] However, there is a trend toward consolidation. According to

- Is the decision maker the building design engineer?

The prevailing **fee structures** for building design engineers cause first costs to be emphasized over life-cycle costs.[55] Projects are often awarded in the first place to the team that designs the least-cost building; their fees are typically reduced if actual construction costs exceed the estimated costs. This schism tends to hinder energy efficiency because initial capital costs are typically higher for the installation of superior heating, ventilation, and air-conditioning systems that reduce subsequent operating costs.

- Is it the electric utility?

Another clear-cut example of market failure lies in **electricity pricing practices.** The electric sector is characterized by a highly variable load that cycles widely over seasonal and daily time periods. The result is a real-time cost of electricity production that can vary by a factor of 10 within a single day.[56] The consumer, however, is not generally aware of the time-of-day or seasonal cost schedule the utility faces. Instead, the consumer sees a monthly electricity bill that is essentially an average monthly cost. Some companies even allow customers to avoid billing spikes in high usage months by averaging costs over entire years such that no price variation is seen. In this case, the consumer is likely to be entirely unaware when production costs are high. These flat rates cause households to over-consume during peak

The question of market failure may be irrelevant

- If you think of a fixed demand curve resulting from conscious decision making, then market failure is a primary lens for examining questions relating to energy efficiency.
- If you think of a Lancaster-type model of demand with product characteristics, with the characteristics that are considered being subjectively determined and context-dependent, market failure is not the only lens that is relevant.
  - Behavior change is a separate lens.

Is "the" demand curve static?

- How much of change in behavior is explained by change in prices and/or income over time?
- How much is explained by other changes, including changes in preferences?

requirements. According to the vice president of research at the National Association of Home Builders, "as family size decreased almost 25 percent over 30 years, the size of new houses increased about 50 percent, to slightly more than 2,300 square feet today, from 1,500 square feet."[3] Second, the range of electric equipment provided in buildings has increased significantly, especially air conditioning in the South and electronic equipment, televisions, and other "plug loads" in buildings nationwide.[4] Central air conditioning is now a feature of 85 percent of homes in the United States, up from 34 percent in 1970.

- What fraction of these changes in house size, air conditioning, number of electricity using appliances, etc. was a conscious, deliberate choice by the current occupant of the home?

Rethinking demand modeling

The locus of decision-making

- Who makes the decision?
  - What is the decision that they are making?
- Whose choice behavior do you want to influence?

What energy uses do I control?
And why would I change them?

- If I get a more energy-efficient electric toothbrush, how likely is it that I will choose to brush my teeth longer? Why would I do that?
- If it is not likely that I brush my teeth for longer, there is no rebound effect.
- If I get an energy-efficient refrigerator, how likely is it that I will choose to utilize my refrigerator in such a sway that my consumption of electricity rises? How would I do that?
  - Is the rebound argument that I buy a larger refrigerator?
    - If so, how do I fit a larger refrigerator into my kitchen?

- Need to identify the users, the uses they control, and the time frame on which they might choose to change them.

What is the choice?

- Conventional economics models the demand for a commodity as though the consumer is constantly re-optimizing his consumption to match current circumstances.
- An alternative approach would focus on modeling when and how demand changes.
  - The assumption is that most of the time, the consumer just repeats what he normally does. He has some existing pattern of demand – "habitual demand"
  - However, sometimes circumstances change sufficiently to attract his attention. He then considers whether to make a change.
  - In the latter case, there are two things to model:
    - If a change occurs, what change will be selected?

Analyses framed around changes

- Literature identifying different price elasticities for small price changes versus large price changes.
  - Suggests the importance of salience. Small price changes not salient, hardly likely to be noticed, therefore evoke little or no response. Large price charges likely to be salience.
- Literature on messaging
  - Comparing your use to that of others like you
    - Shown to induce reductions on the order of 3-4% in electricity use
    - Messaging with electricity bill

An analysis framed around changes

- How many households confront change (participate in experiment, etc)?
  - What percent of total users?
- What is the possible nature of the response
  - CHANGE IN STOCK
  - Change in appliances (refrigerator, dishwasher,etc)
  - Retrofit part of house – air conditioning, heating, lighting, kitchen
  - CHANGE IN UTILIZATION OF STOCK
  - Change in behavior – use appliances less
- The two types of response may be motivated by different factors, and may play out on different time scales.

The timing of behavioral response

- We assume continuous decision making. That might be appropriate if households rented their energy-using equipment. But, this is not what happens.
- For decisions involving capital stocks of energy-using equipment, the issue of timing is a huge problem.
- Some specific event is likely to trigger a decision on making a change
  - When you move into the house
  - When the item breaks down
  - When a subsidy program or some other intervention occurs
  - When there is publicity or some other event that makes this a salient issue.
- Perhaps most of the action lies with the timing of choice rather than the nature of the choice.
  - A choice experiment creates an artificial situation with regard to the timing of choice.

Approaches to accounting for heterogeneity

- Heterogeneity is a fundamental feature of residential energy demand. How can this be factored into the analysis?

  - Condition on characteristics of the structure and/or the people
  - Random coefficient demand models (discrete/continuous choices)
  - Frontier demand model approach

Towards a bounding analysis

- What percent of energy users is likely to be affected?
- What aspects of their energy use is likely to change? What percent of their usage might be changed?
- How much could the resulting change be in energy demand?

- The idea is to put an upper bound on how much change in usage could occur, over what time period.

A frontier approach to estimation

- Standard statistical modeling aims to estimate an average E{y|x}
  - $y = X\beta + \varepsilon$, where ε ranges from negative to positive
- An alternative focuses on estimating the best-practice frontier
  - $y = X\beta + \varepsilon$, where $\varepsilon \geq 0$.
  - In some formulations the variance of ε may be a function of variables, such as price (the higher the price, the closer actual practice is to best practice?)
  - Requires individual level data.

Breaking down the data

- The key to making sense of residential energy demand is to decompose it. There are several ways to do this:
  - Conditional on end use
  - Conditional on housing type
    - Newly built home versus existing home or by home vintage
    - Conditional on housing characteristics
    - Conditional on types of appliances installed
  - Conditional on user type
    - Household characteristics (size, income, etc) for occupant
    - Household characteristics for neighborhood (sorting model, peer effects)
  - Conditional on timing of an event
    - Change of ownership, new owner vs existing owner
    - Conditional on policy intervention – price change, rationing, etc
    - Conditional on receipt of a nudge

An analogy to a “wedges” analysis

- In the climate change literature, the engineers have popularized an approaches framed around wedges – discrete blocks of GHG reduction associated with particular physical or policy changes.
- By analogy, the analysis of energy demand could be framed around “blocks” of demand associated with
  - Specific types of user
    - Families with no children vs families with small children
    - Families that have recently moved into a new home versus those who have lived for a long time in the home
  - Specific end uses
    - Air conditioning, etc
- The notion is that there is a separate demand function for each block of demand.

Two interesting recent papers

WHY HAS CALIFORNIA'S RESIDENTIAL ELECTRICITY CONSUMPTION BEEN SO FLAT SINCE THE 1980S?: A MICROECONOMETRIC APPROACH

Dora L. Costa
Matthew E. Kahn

Working Paper 15978
http://www.nber.org/papers/w15978

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
May 2010

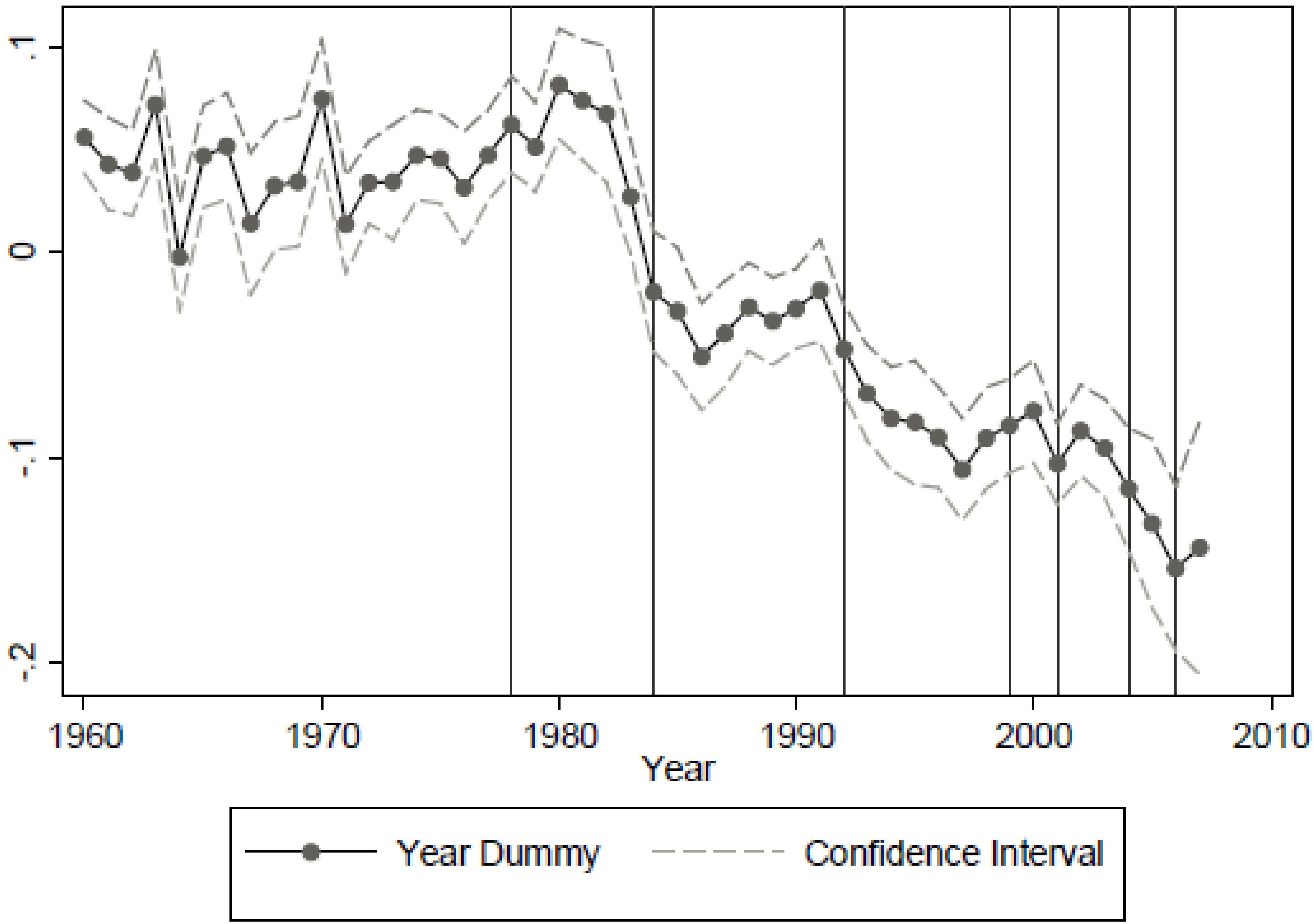
Distinctive features of study

- Household level billing data for every home in county, 2000-2009.
  - Kwh purchased per billing cycle, whether house uses electric heat, whether enrolled in renewable energy program
- Combine with weather data
- Merge with 2008 & 2009 credit bureau data
  - Household income, ethnicity, age of head of household, number of people, year house built, size of house, whether has a pool.
- Merge with voter registration data
- Merge with marketing data

1) $$\ln(kWh) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \varepsilon$$

where $X_1$is household income; $X_2$is a vector of demographic, ideological, and other characteristics including age, ethnicity, whether Spanish is spoken at home, the year the household moved into the house, the number of persons in the household, the party of registration, whether the household donates to environmental organizations, whether the household purchases energy from renewable resources, and the special utility rate of the household (medical assistance or energy assistance); X_3 is a vector of house characteristics (square footage, electric heat, roof type, and whether the house has a pool); X_4 is a vector of census block group characteristics, consisting of the fraction of registered voters who were "liberal" (Democrats, Green Party, or Peace and Freedom) in 2000 and the fraction of registered vehicles that were hybrids in June 2009; X_5 is the mean of daytime and nighttime temperature in the billing cycle (we also examine the interaction between liberal and mean temperature); $X_6$is a vector of building year dummies (single years with pre-1960 as the omitted category); and, ε is

Figure 1: Effect of Year Built on Mean Daily Kilowatt Hours Purchased by Households in Calendar Year 2008



Movers 2008-2009

- Costa & Kahn did a separate analysis of houses where the occupant moved during 2008 or 2009.
- They know the energy used by the family in its old home and its new home.
- They know the energy used in the home with the old occupant and the new occupant.
- They exploit this information to identify the influence of the house versus the people on energy use

Movers and Renovators

Our panel data show that while a house is energy inefficient both because of its structure and the people living within it, the house itself accounts for a larger share of the variance in total electricity purchases (see Table 6). Our analysis of variance shows that in a random sample of movers moving to different homes within the utility district between 2000 and 2008, the partial sum of squares for the residence is more than three times larger than the partial sum of squares for the family in July, the hottest month of the year, and the partial sum of squares for the residence is more than two times larger than the partial sum of squares for the family in December, the coldest month of the year.

A rebound effect associated with home renovation. Is this a surprise? Why else would they remodel?

How much is a house's energy efficiency determined by its year of birth, or can a home renovation change the energy efficiency of the dwelling? Table 8 shows that most renovations increase energy consumption. A new HVAC decreases electricity purchases for mean temperatures below 58.3°F or 14.6°C (roughly the 35th bottom mean temperature decile). At a temperature of 75°F (23.9°C) a new HVAC increases electricity purchases by 5 percent. This finding is consistent with past work documenting a rebound effect associated with new residential durables purchases (see Dubin, Miedema and Chandran 1986, and Davis 2008). Additions of square footage and new kitchens increase daily kilowatt hours purchased by 1.4 and 1.7 percent, respectively. A new roof decreases electricity purchases by 1.6 percent.

Deconstructing the ‘Rosenfeld Curve’: Why is Per Capita Residential Energy Consumption in California so Low?

Anant Sudarshan, Stanford University

USAEE-IAEE WP 10-063

December 2010

- Sudarshan estimates a set of (log) demand functions for households in California and other states using the RECS household level data for 2001 and 2005

The expressions for $x_{e,t}$ and $x_{h,t}$ in can be written as follows (following the expression derived in 3). Note that here Z_t has been separated into $[Z_t^{'} CA_t]$ where the first block is a matrix of demand modifiers (see Table 1) and the second is a vector of dummy variables (CA_t) which is 1 when the household is located in California and 0 otherwise.

$$
\begin{aligned}
y_{e,t} &= \ln(x_e) = \beta_{e,t}^{'} Z_t^{'} + \delta_{e,t}(CA) - \theta_{e,t} P_{e,t} + \epsilon_{e,t} \\
y_{h,t} &= \ln(x_h) = \beta_{h,t}^{'} Z_t^{'} + \delta_{h,t}(CA) - \theta_{h,t} P_{h,t} + \epsilon_{h,t}
\end{aligned}
$$

The conditioning variables for household types

Demand Equation	G_e: Type Characteristics (Electricity)	G_h: Type Characteristics (Secondary Fuel)
Intercept	Intercept	Intercept
Cooling and Heating Degree Days	Electric Air-Conditioning	Electric Water Heating
Price (Electricity)	Electric Water Heating	Electric Heating
Price (Secondary Fuel)	Electric Heating	Home Ownership
Housing Unit Floorspace	Durables Ownership	Very Low Income
Household Size	Home Ownership	Time (Absent in $\tilde{G}$)
Housing Unit Age	Very Low Income	
Occupancy Dummy	Time (Absent in $\tilde{G}$)	
Urban/Rural Location		
California Dummy		

Table 1: Model covariates in demand function (left column) and heterogeneity segmentation for the two fuels (right columns). Number of types estimated from the data: 97 (electricity demand model), 31 (secondary heating fuel model).

Coefficient estimates by type

Parameter Variation with Type Characteristics in Electricity Demand Equation													
	Intercept	HDD	CDD	HomeArea	HHMembers	OldHouse	NewHouse	AtHome	HHAge	Rural	Urban	CA (δ)	PriceCoeff
Intercept	7.94**	0.09	0.40**	0.23**	1.05**	-0.06**	-0.16**	0.03	0.03	0.10**	-0.04	-0.13**	-2.35**
Electric Air-Conditioning	0.50**	-0.35**	0.25**	0.02	-0.10**	0.02	0.06*	0.02	-0.03	-0.03	-0.02	-0.09**	-1.60**
Electric Water Heating	0.46**	0.20**	-0.33**	-0.02	0.17**	-0.02	0.01	-0.01	-0.01	-0.04	-0.02	-0.01	-0.57**
Electric Heating	0.35**	0.03	-0.19**	0.05*	-0.11*	0.02	-0.06*	-0.05*	0.01	-0.02	-0.01	-0.05	-0.83**
Durables	0.39**	-0.04	0.08	-0.10**	0.06	0.02	0.05	-0.01	0.01	0.04	-0.02	0.08**	-0.58**
Home Ownership	0.43**	-0.21**	-0.24**	-0.08**	-0.01	-0.04	-0.06	-0.01	0.01	-0.04	0.02	0.01	-0.84**
Low Income	-0.03	-0.04	-0.11*	0.01	0.08	0.06**	0.05*	0.00	-0.07**	0.02	0.05*	-0.06*	0.03
Time	-0.01	0.05	0.13**	-0.04*	0.06	0.00	0.08**	0.02	-0.07**	0.01	-0.01	-0.07**	NA
Units	1	10000 DD	5000 DD	1000 sq.ft	10 persons	1	1	1	50yrs	1	1	1	1 cent/KWh

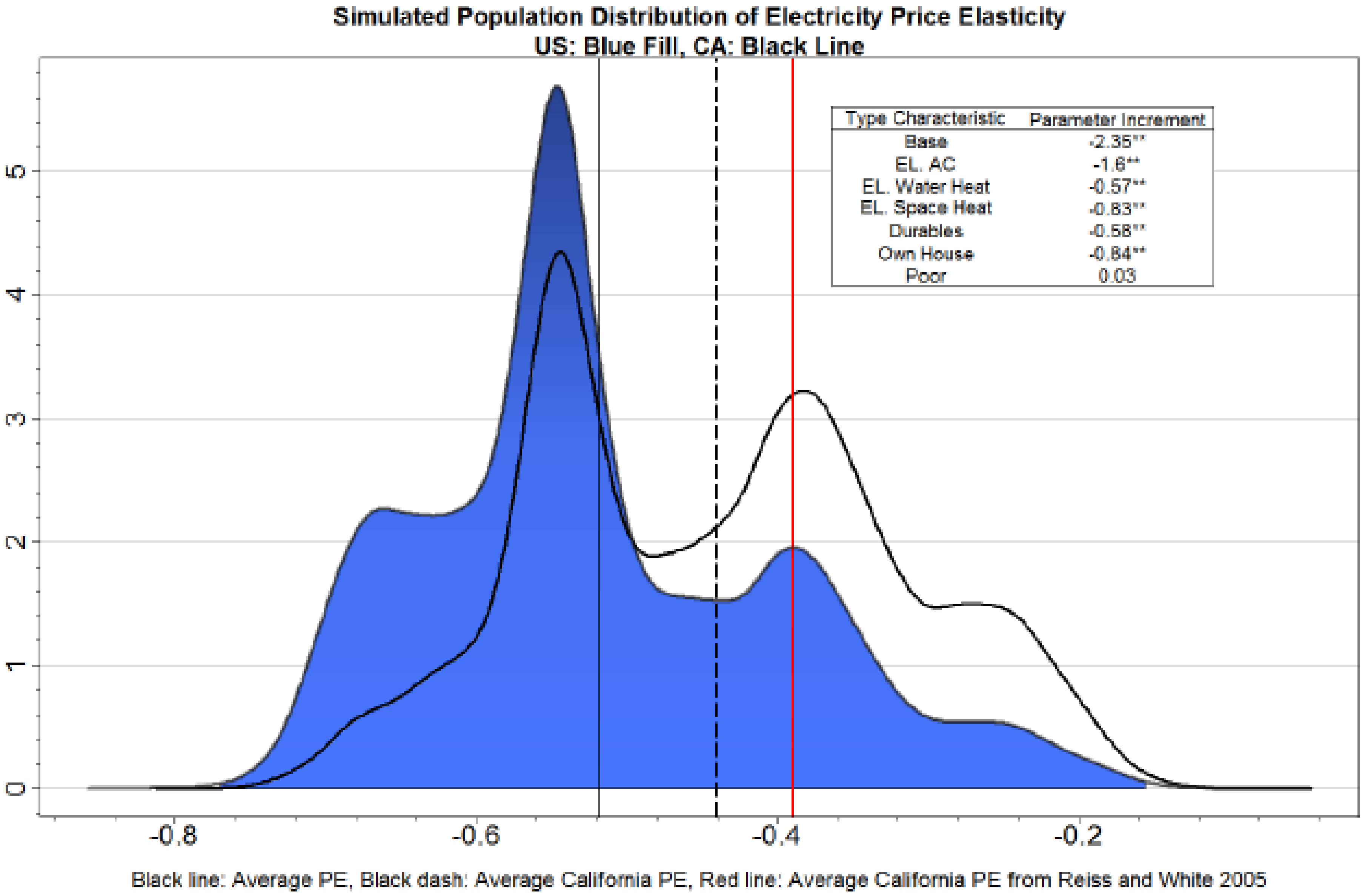


Figure 6: Variation in price elasticity across household types. Elasticities are computed from price coefficient estimates assuming an average price of 10 cents per KWh. Average elasticity for California and the US population differs due to differences in type distribution.

- THANK YOU

Sudarshan’s result

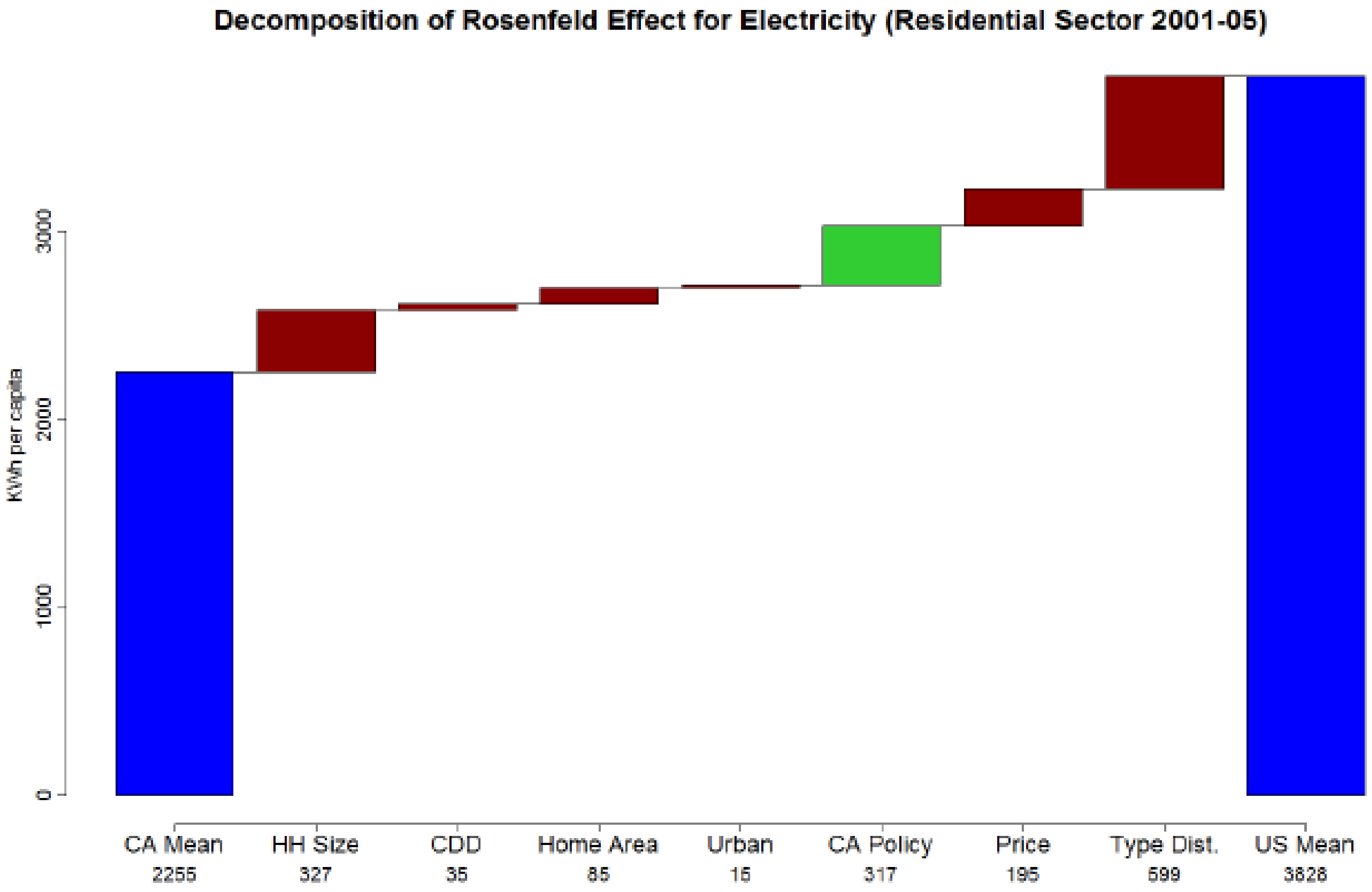
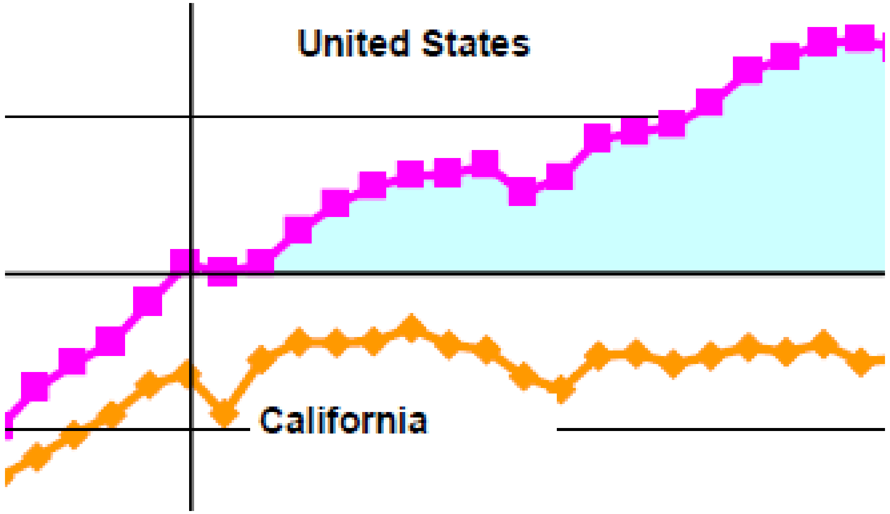


Figure 8: A decomposition of the difference between California and the rest of the country in per capita electricity consumption. Numbers at the bottom are block heights in annual KWh per capita. The green block is the bound on California program effects (the δ dummy).

- This shows that, with regard to the difference in per capita electricity use between California and the rest of the US in 2001-2005, the differences in households types account for more than the policy initiatives in place in California at that time.
- But, this is the wrong question.
- The real question is why did demand level off in

  California in the mid-1970s?



Double Moral Hazard and the Energy Efficiency Gap

Louis-Gaëtan Giraudet (CIRED)
Sébastien Houde (U. Maryland)

Energy Efficiency Gap Workshop – Mannheim – March 13th, 2014

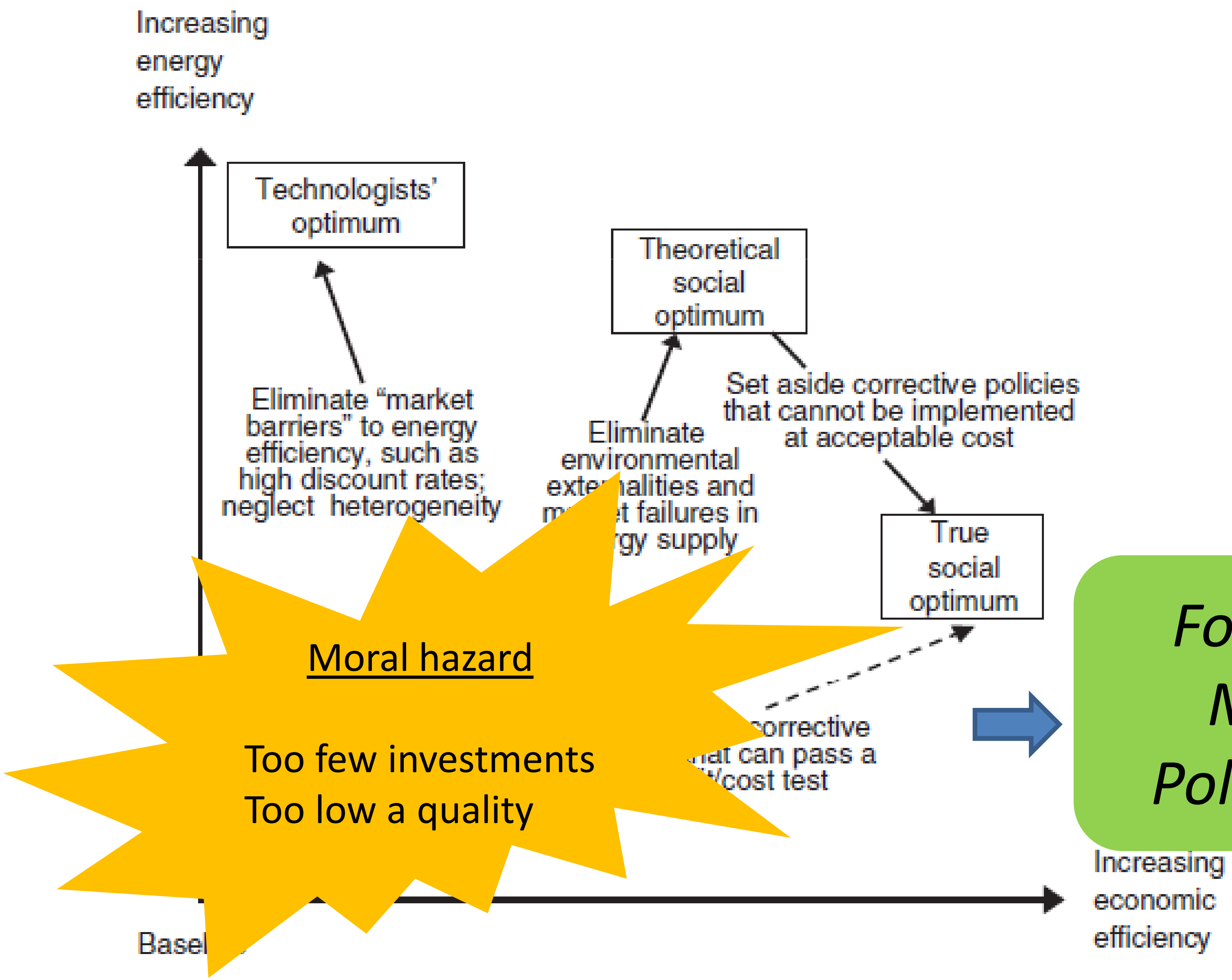
Moral Hazard: *e.g.* Home Energy Retrofit

2013 Winner
"Best Construction Defect" Photography Contest
Awarded by AQC, the French Construction Quality Agency

check out more! http://www.qualiteconstruction.com/manifestations/concours-photo/2013.html

The Energy Efficiency Gap

Jaffe, Newell, Stavins (2004)



Formalization?
Magnitude?
Policy solutions?

Model

Two Hidden Actions

Energy consumption for space heating

$$E(s,q)$$

Homeowner's **energy service**

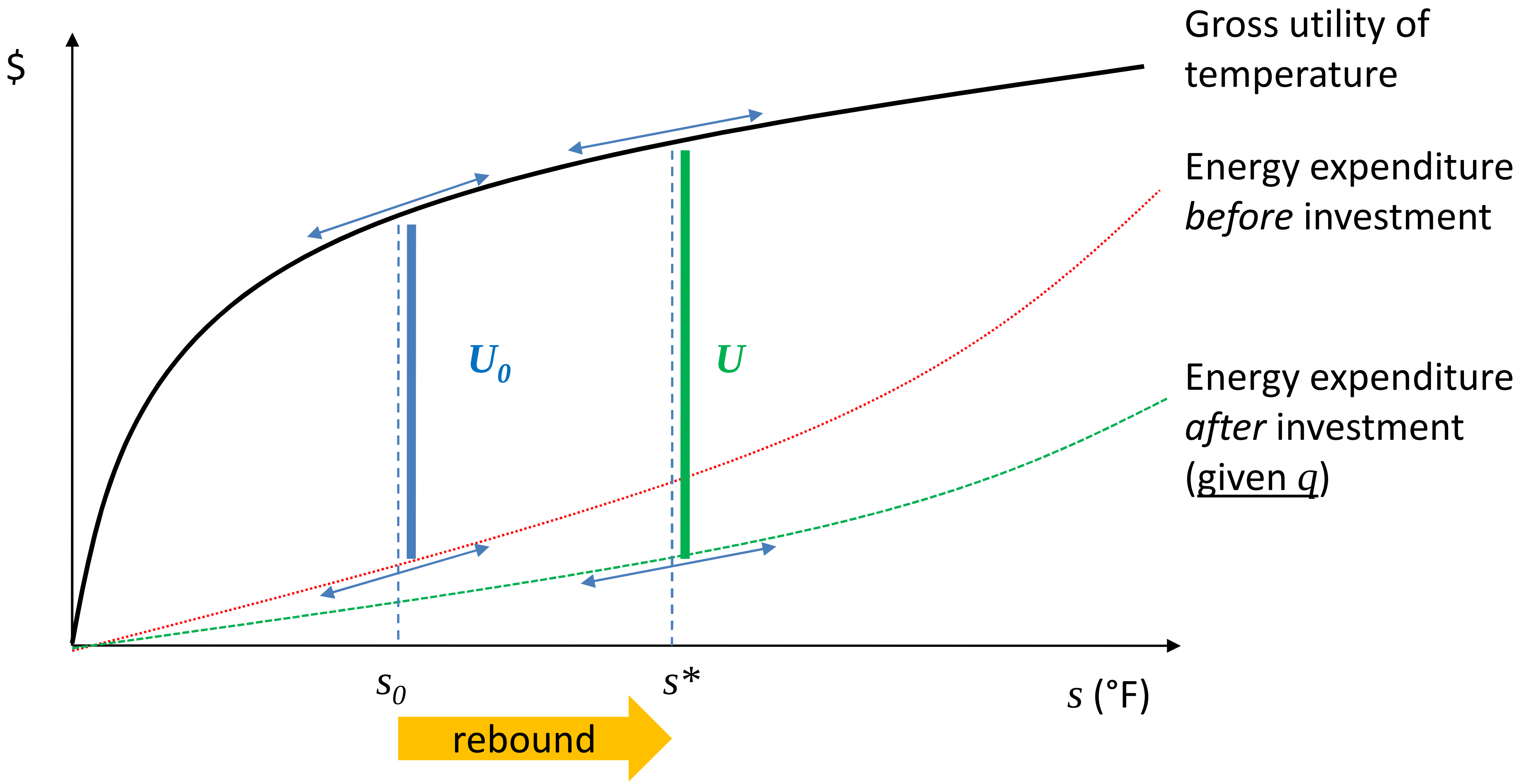
→ *unobservable to the contractor*

Contractor's **quality** of installation

→ *unobservable to the homeowner*

Consumer sets *s*, given *q*

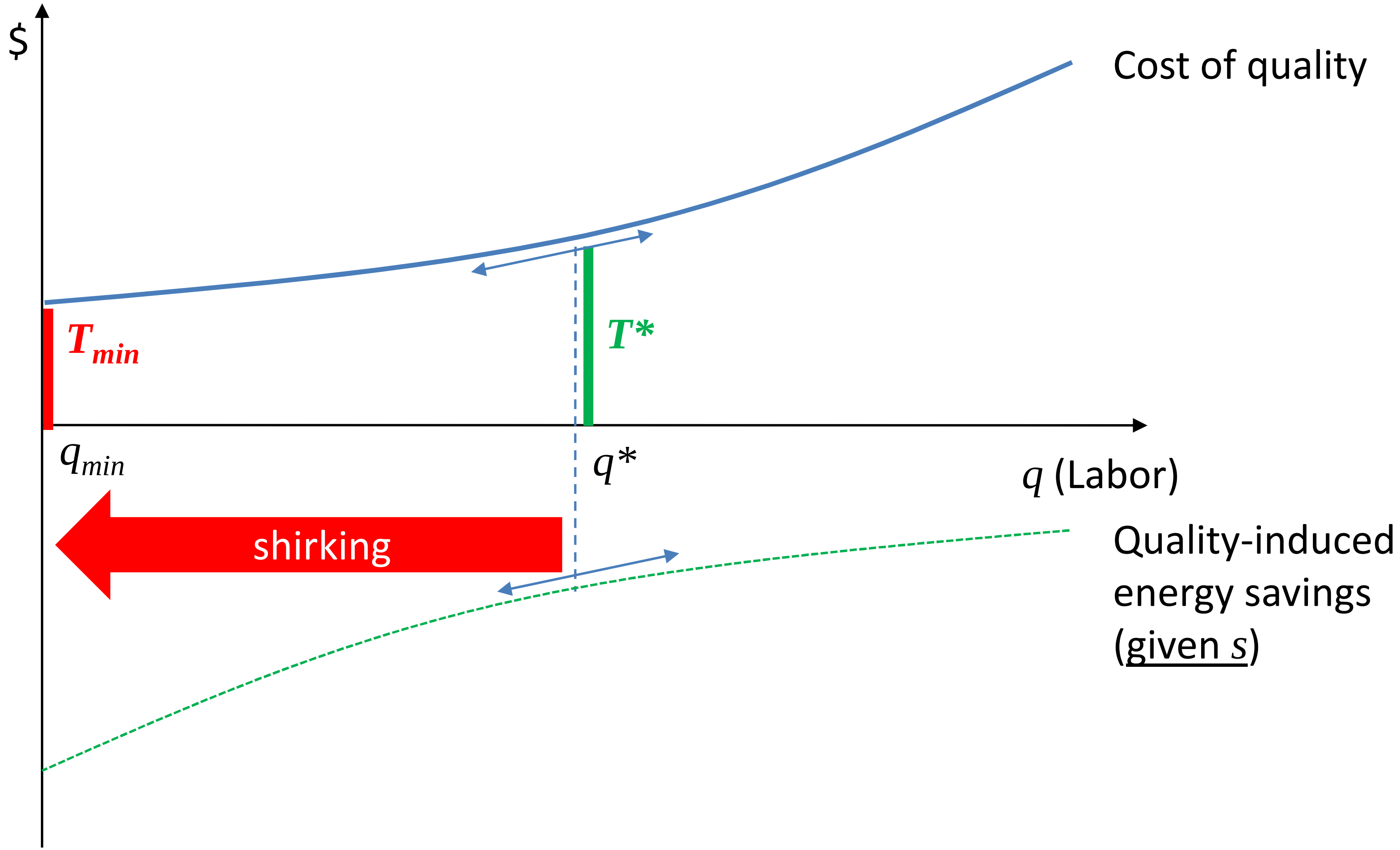
Stage 2



Stage 1 Participation iif $U - U_0 \geq T$

Firm sets q, given s

Stage 2

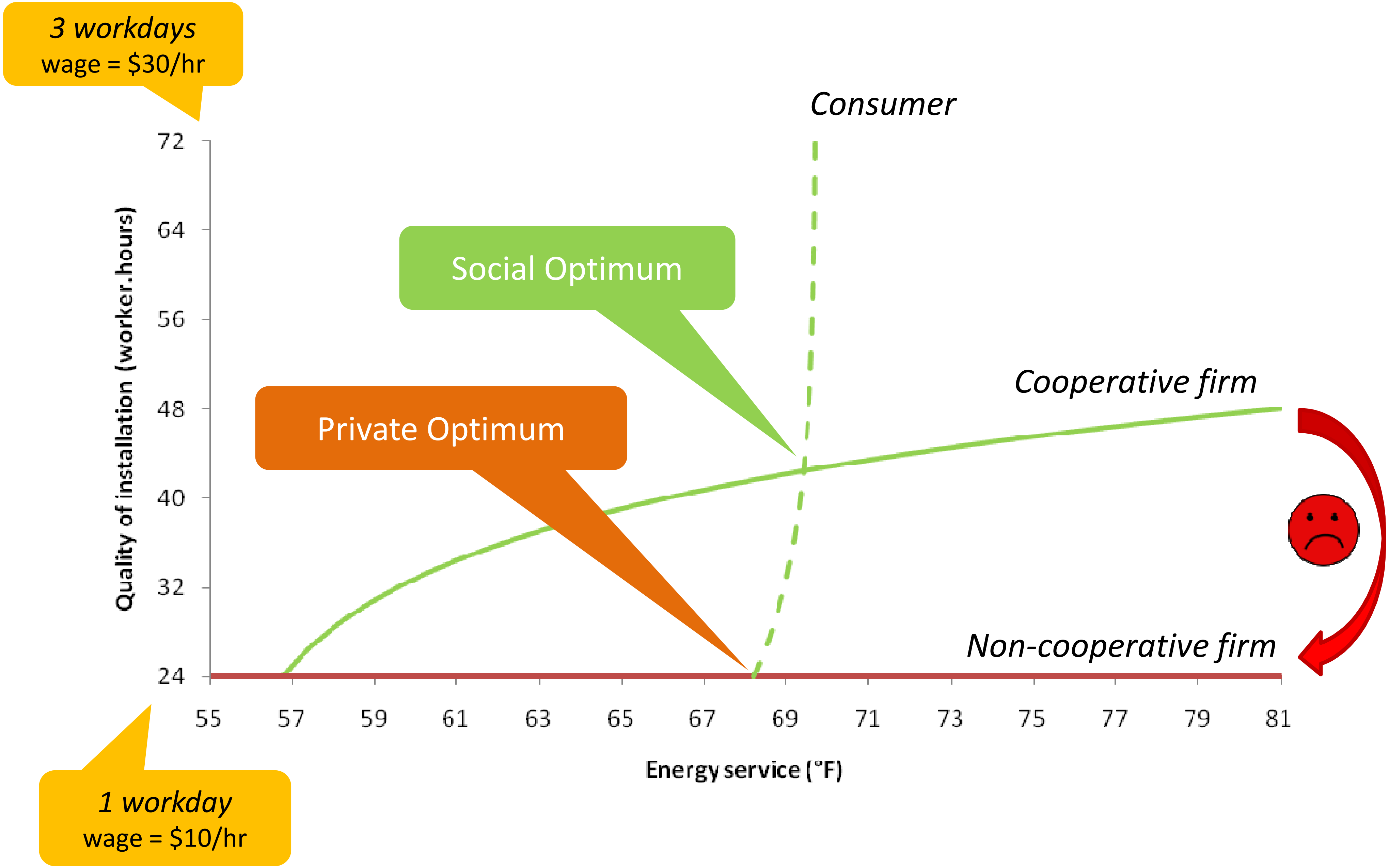


Stage 1

$$\underbrace{T = C(q)}_{}$$

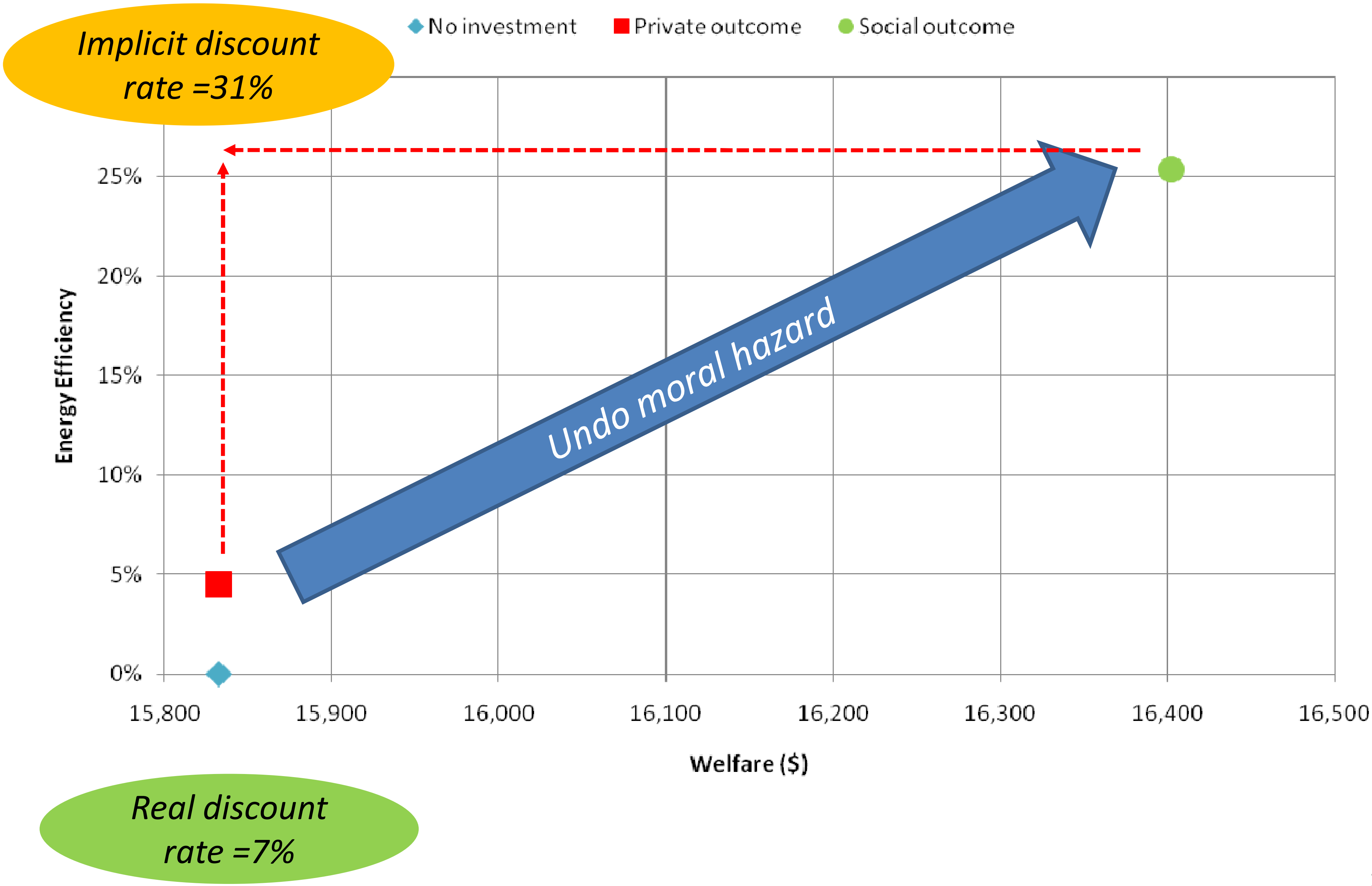
Perfect competition assumption

Reaction Functions Equilibria (*e.g.* insulation)

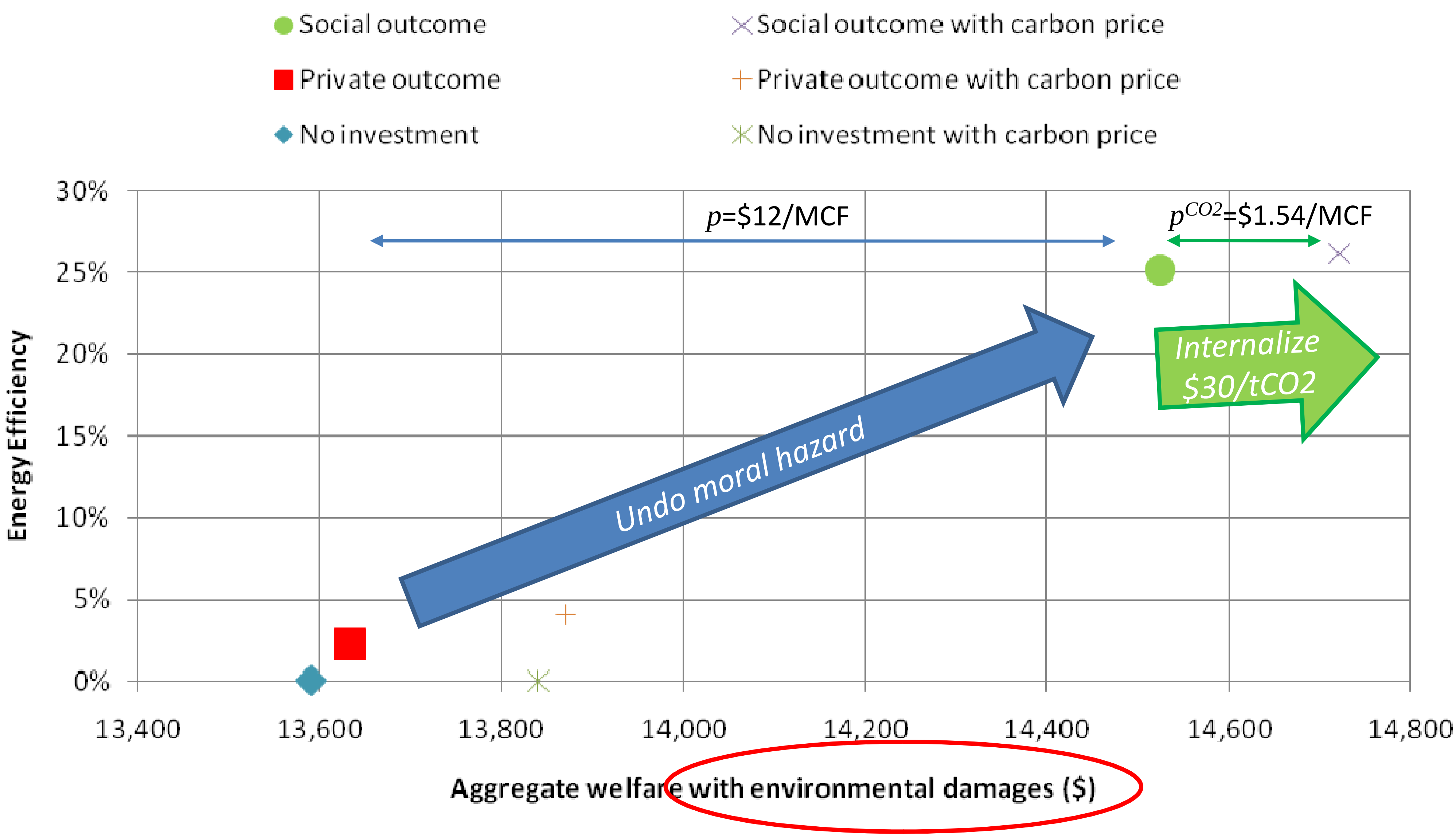


Magnitude

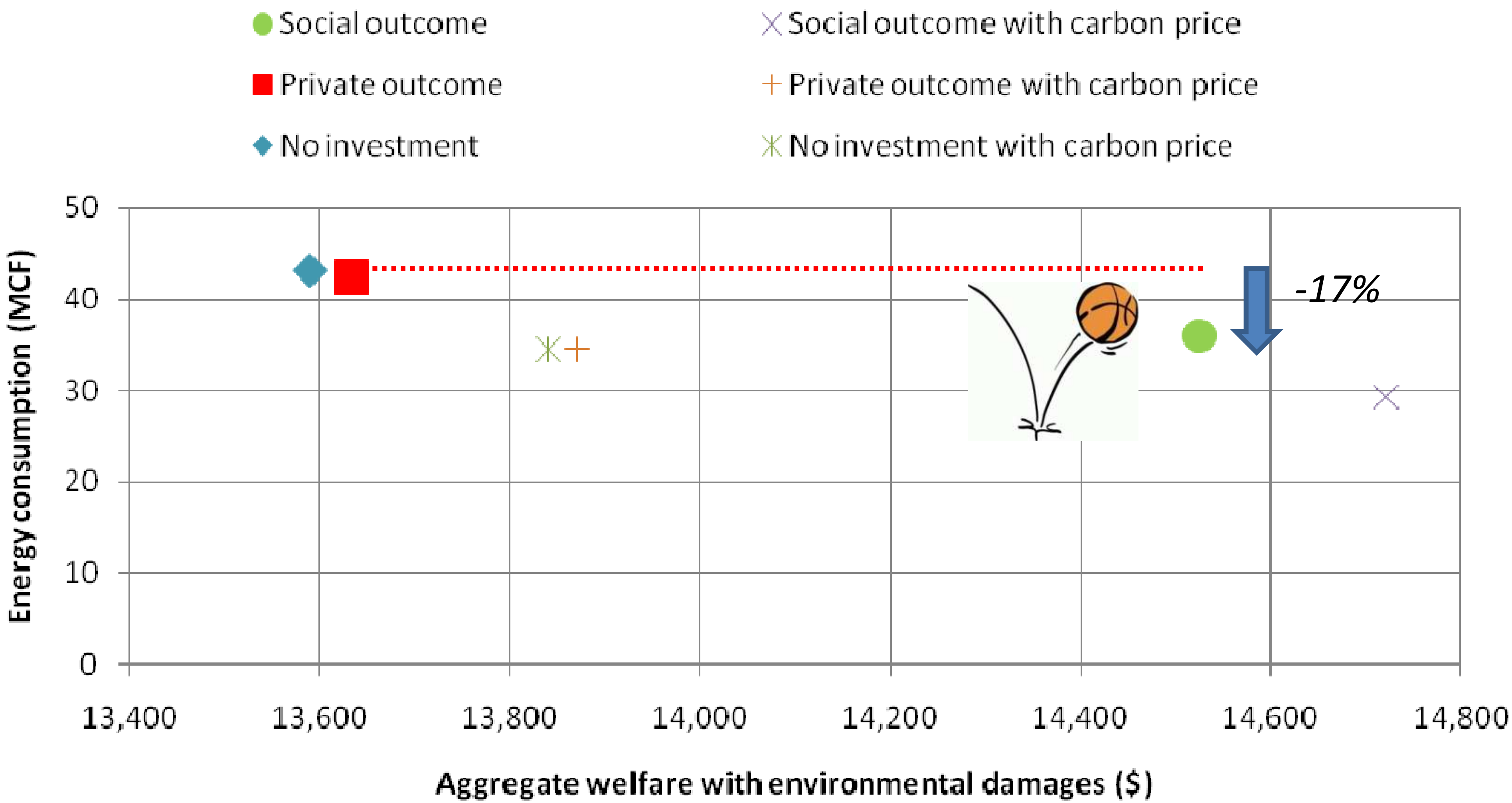
Energy Efficiency Gap



Moral Hazard and Environmental Externalities



Energy Gap and the Rebound Effect



***Sufficient** condition for **joint** intervention: **No 'backfire'** rebound effect*

Policy solutions

Remedies Found in the Marketplace (U.S.)

Voluntary certifications

BUILDING PERFORMANCE INSTITUTE, INC.
HEALTH AND SAFETY, DURABILITY, ENERGY EFFICIENCY, COMFORT
BPI ™
CERTIFIED PROFESSIONAL

SETTING THE STANDARDS FOR QUALITY
RESNET
Residential Energy Services Network
RESNET RATER MEMBER

Incentives

40% energy savings guarantee

UP TO 30% ENERGY SAVINGS GUARANTEED!

GREENHOMES GUARANTEE
at least 25% ENERGY SAVINGS

Calculate Your $avings Now!
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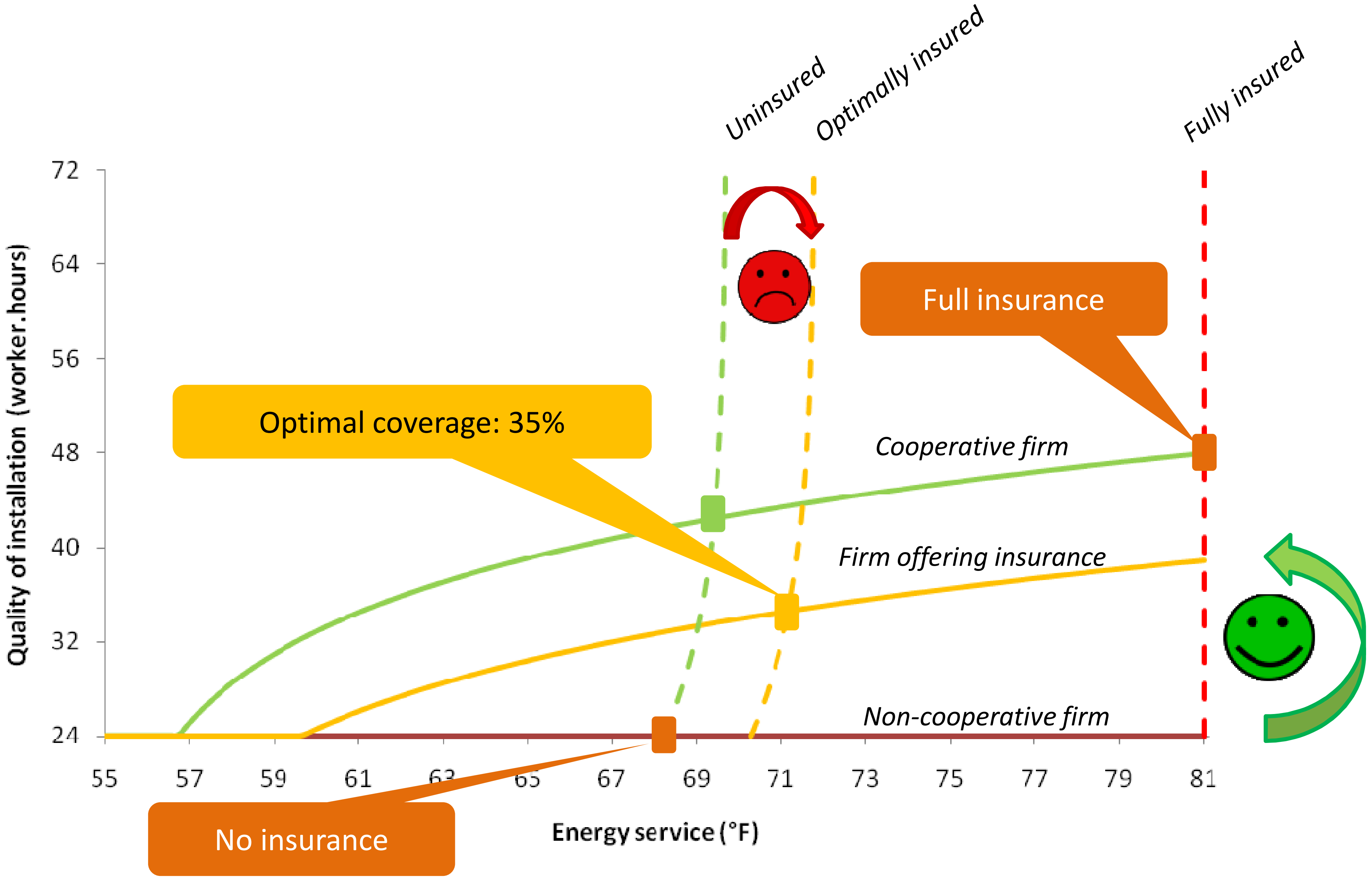
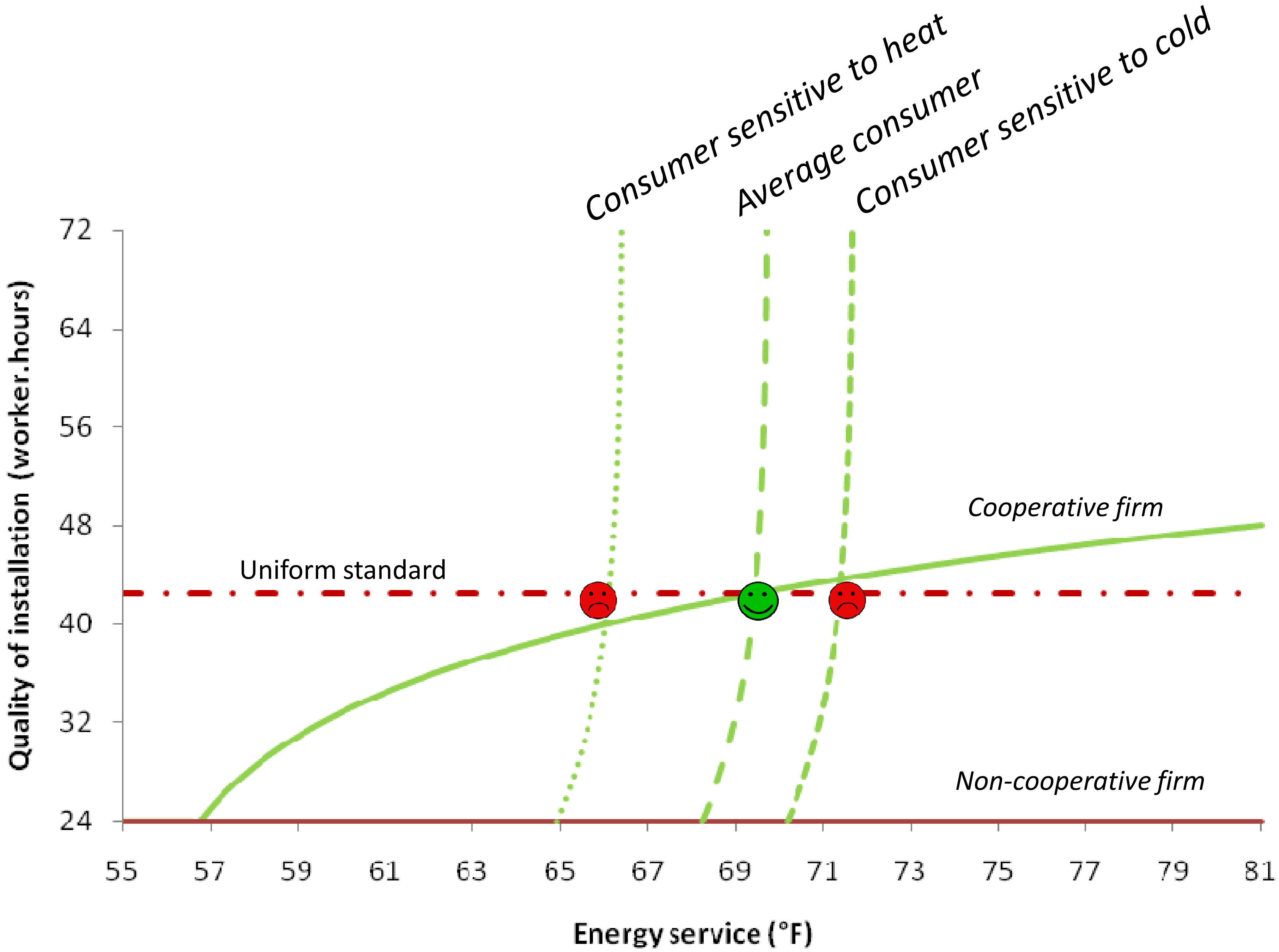
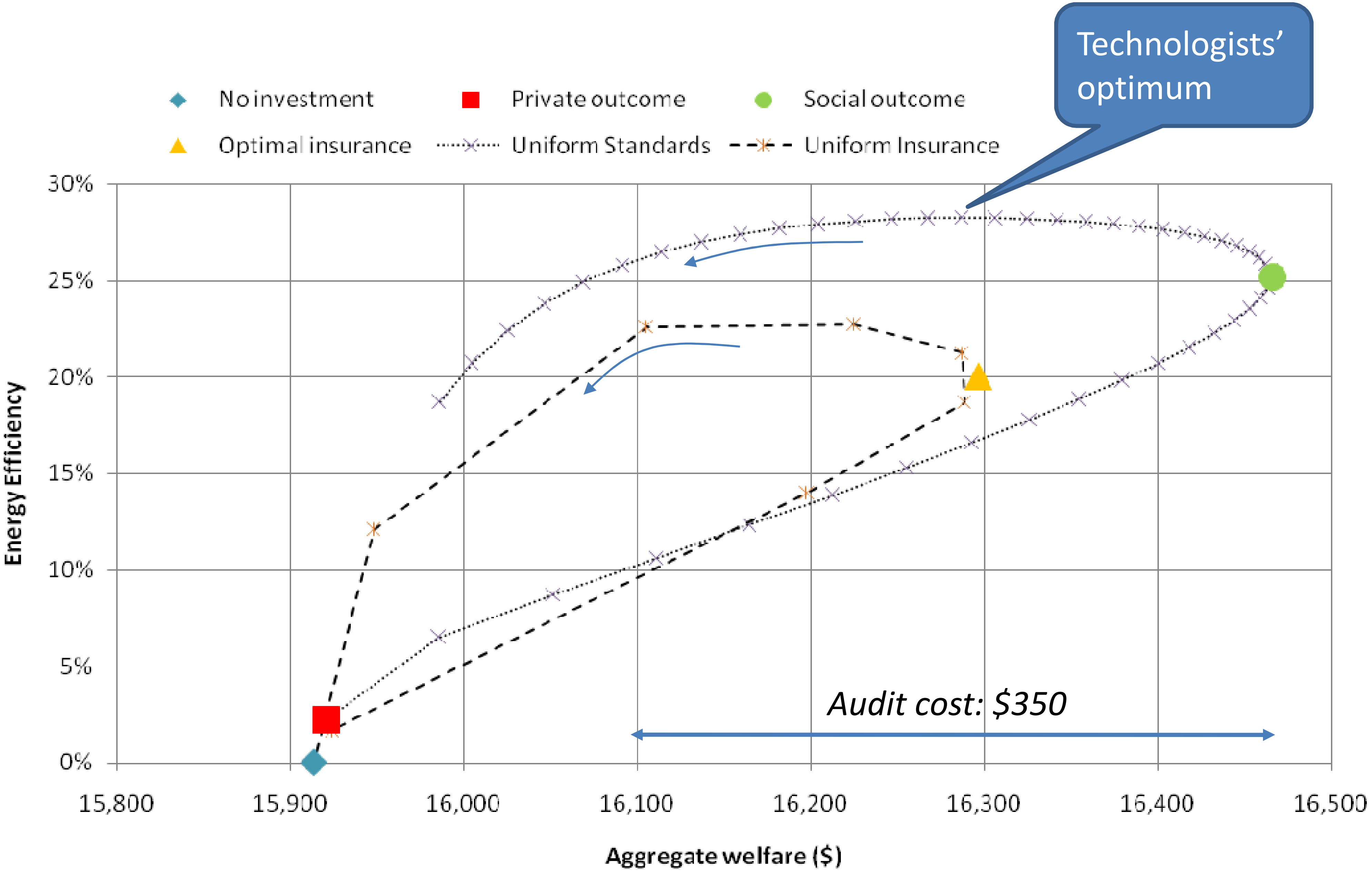
Energy-Savings Insurance



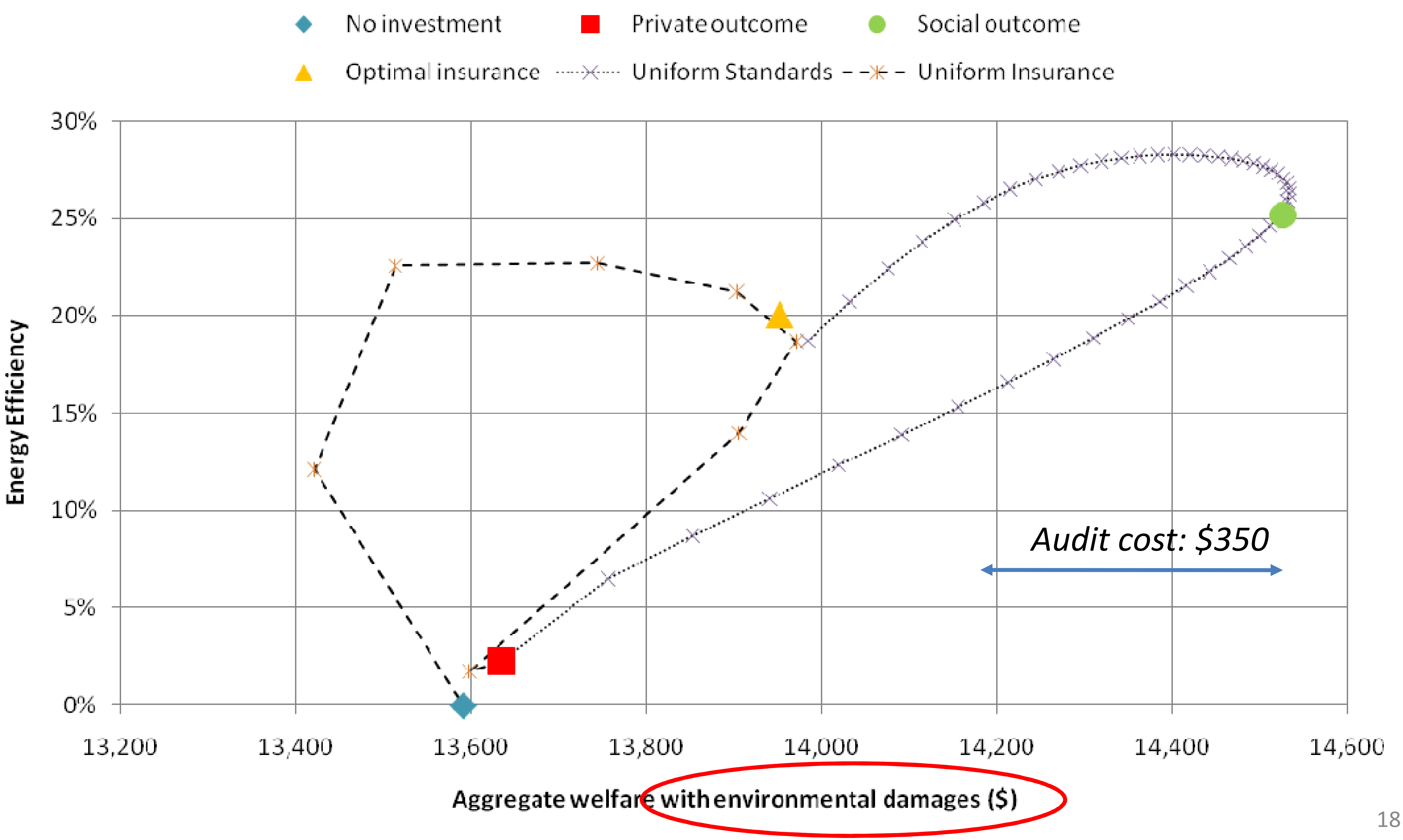
Quality Standard



Uniform Standards and Insurance



Policy Tools with Environmental Damages



Conclusions

Assuming perfect rationality and risk-neutrality…

⇒ *Formally*, moral hazard can cause an energy efficiency gap: too low a quality, too few investments

⇒ *Quantitatively*, it is probably larger than the gap induced by environmental externalities

⇒ *Policy solutions* are only second-best because moral hazard is two-sided

Perspectives

Empirical Analysis

Issue of data availability

Heterogenous firms

→ Price dispersion

Repeated game

→ Reputation

Supplementary Material

MODEL: Objective Functions

(concave) value of energy service

energy bill

Homeowner's utility $$U(s,q) \equiv \sum_t \left[V(s) - pE(s,q) \right] \delta^t - T$$

tariff of the sale

Contractor's profit $$\Pi(q) \equiv T - C(q) = 0$$

(convex) cost of quality

zero profit condition

MODEL: Social *vs.* Private Optimum

Social, cooperative setting (*)

$$\underset{s,q}{Max}\left[U(s,q)+\Pi(q)\right] \xrightarrow{\text{F.O.C}} \begin{cases} V'(s)=p\dfrac{\partial E}{\partial s} \quad \forall t \\ C'(q)=-\sum_t p\dfrac{\partial E}{\partial q}\delta^t \end{cases}$$

Agents set optimal effort so that marginal benefit equates marginal effect on energy bill

Private, non-cooperative setting (#)

$$\begin{cases} \underset{s}{Max}\, U(s,q) \\ \underset{q}{Max}\, \Pi(q) \end{cases} \xrightarrow{\text{F.O.C.}} \begin{cases} V'(s)=p\dfrac{\partial E}{\partial s} \quad \forall t \\ q=\underset{q\geq q_{\min}}{\arg\min}\, C(q)=q_{\min} \end{cases}$$

The contractor does not internalize the benefits his action delivers on the energy bill

MODEL: Objective Functions with Insurance

Contractor bears a share k of the risk

e.g. pays any shortfall in energy savings below a pre-agreed baseline

$$\begin{cases} \Pi(q) \equiv T - C(q) - k \sum_t pE(s,q)\,\delta^t \\ U(s,q) \equiv \sum_t \left[V(s) - (1-k)\, pE(s,q) \right] \delta^t - T \end{cases}$$

MODEL: Insurance Optimum

Second stage of the game is non-cooperative

$$\begin{cases} V'(s) = (1-k)\,p\dfrac{\partial E}{\partial s} & \forall t \\ C'(q) = -k\sum_t p\dfrac{\partial E}{\partial q}\delta^t \end{cases}$$

*Consumption of energy service is **optimal** if the homeowner is NOT insured **(k = 0)***

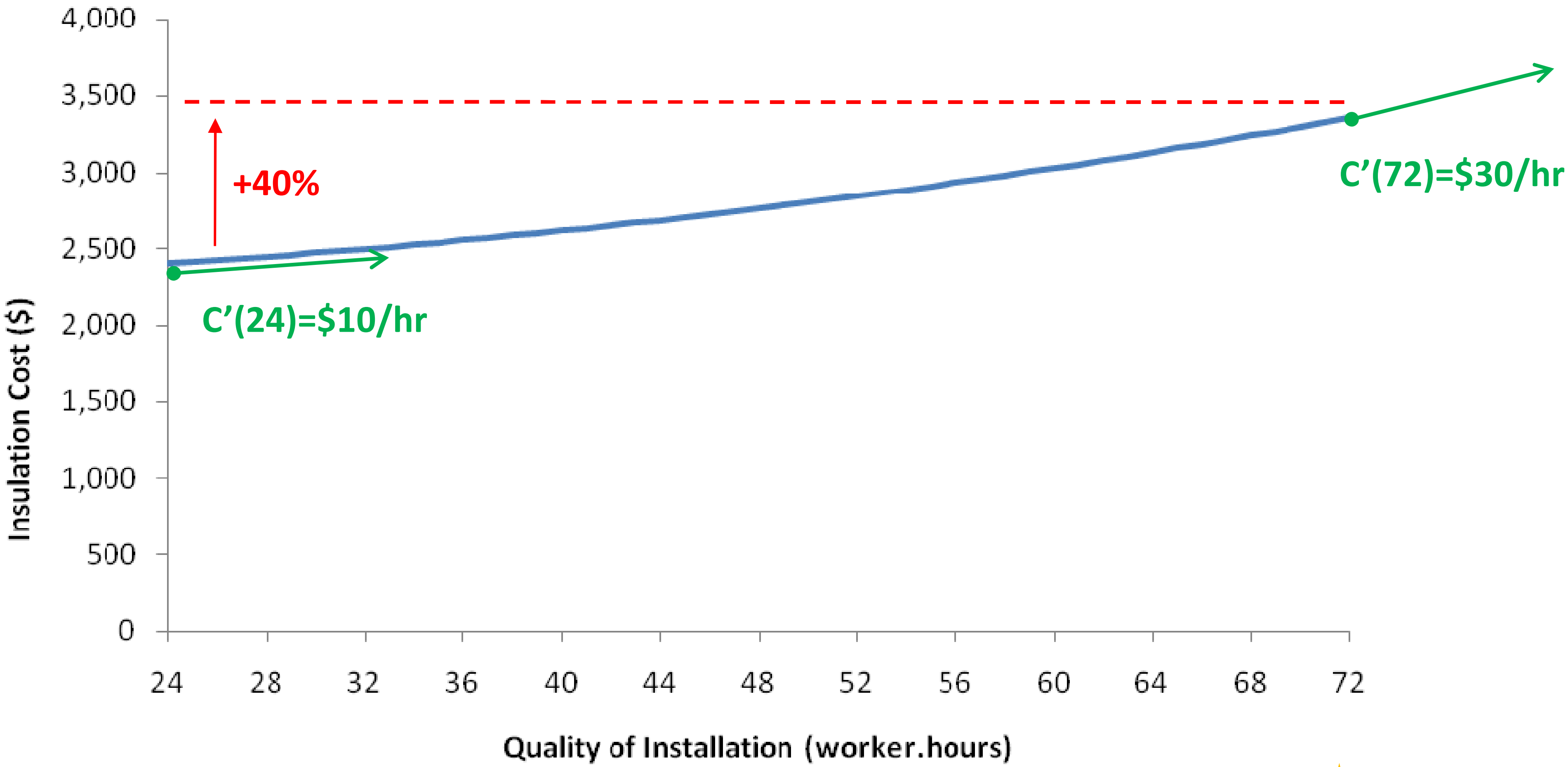
Contract necessarily **incomplete**

*Contractor provides **optimal** quality if he FULLY insures the energy savings **(k = 1)***

First stage of the game is cooperative

$$\underset{k}{Max}\left[U\left(\hat{s}(k),\hat{q}(k)\right)+\Pi\left(\hat{q}(k)\right)\right] \longrightarrow \hat{k}$$

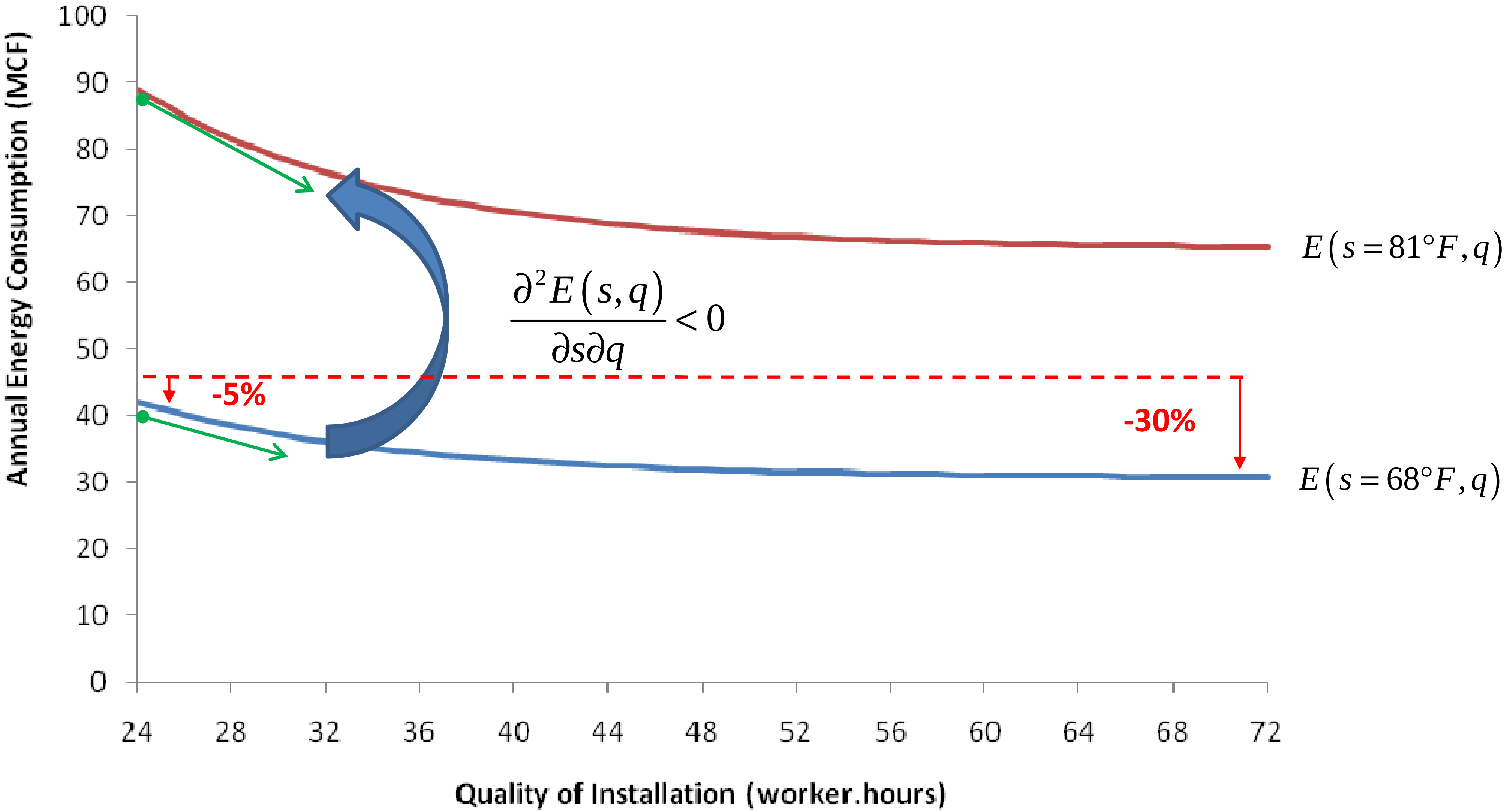
CALIBRATION: Insulation cost



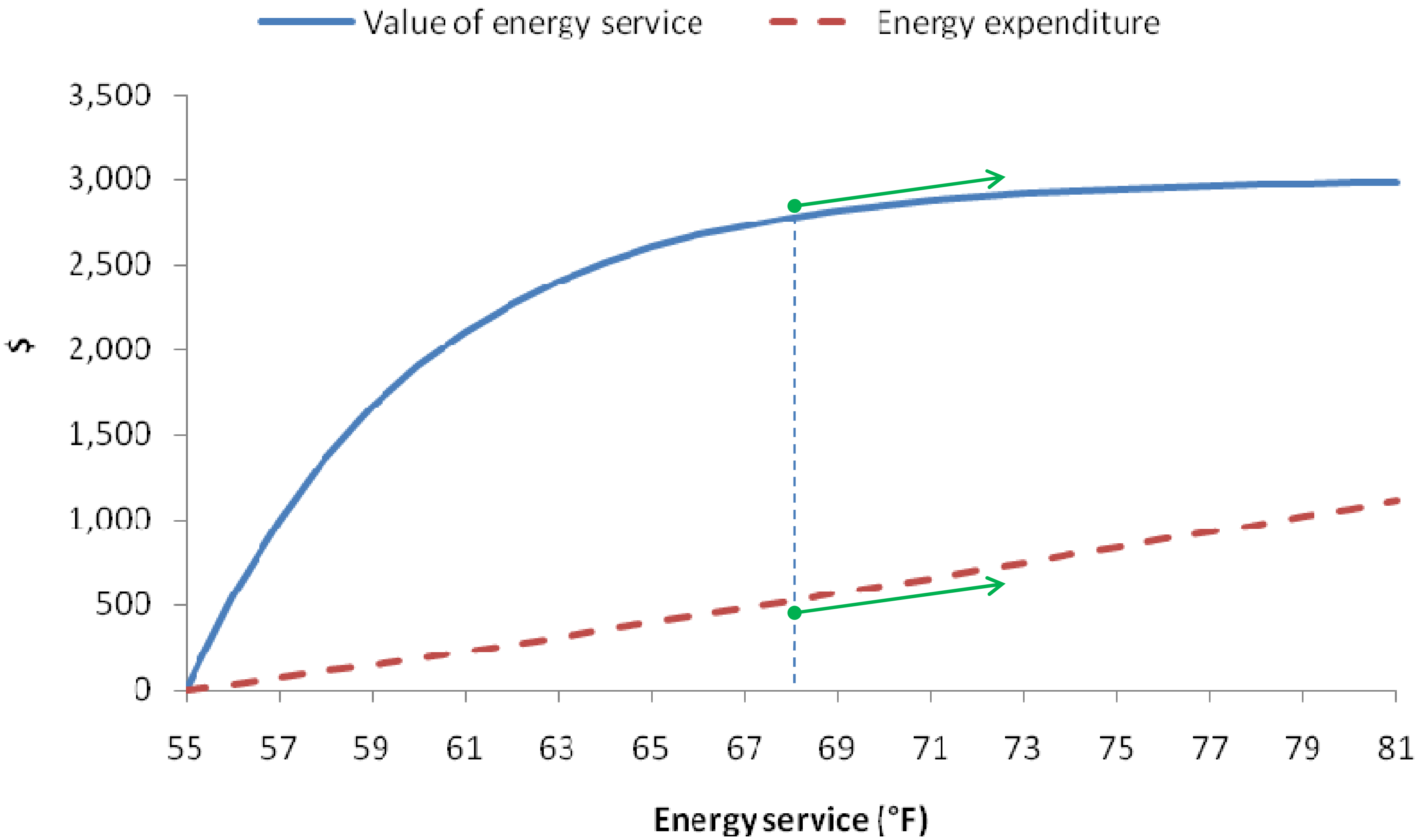
1 workday = 3 installers working 8 hours each

3 workdays

CALIBRATION: Natural Gas Consumption

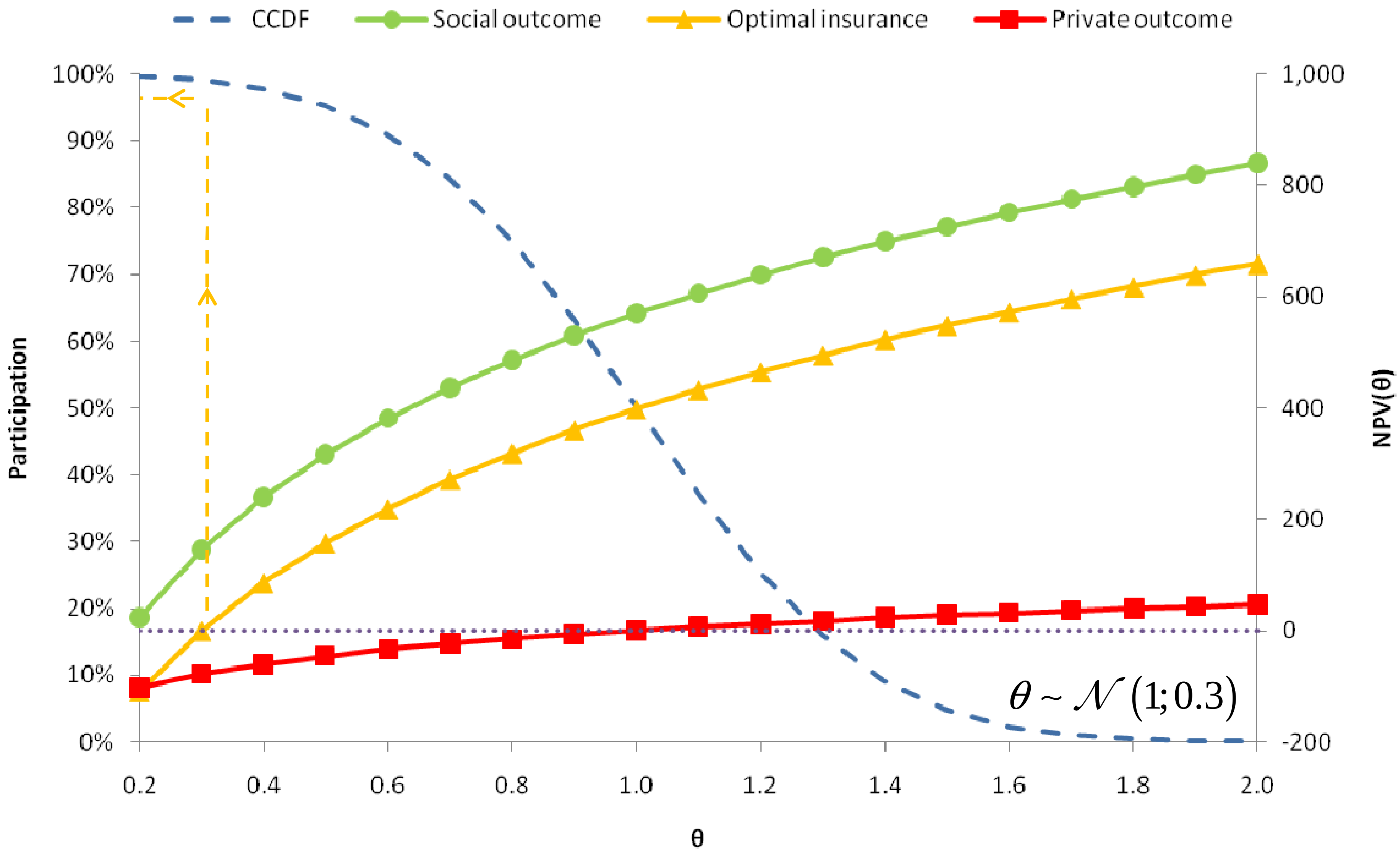


CALIBRATION: Utility



CALIBRATION: Consumer Participation

$$NPV(\theta) \equiv U(\theta) - T(\theta) - U_0(\theta)$$



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- http://www.polyvore.com/cgi/img-thing?.out=jpg&size=l&tid=40887891

Modeling energy efficiency scenarios

Johannes Emmerling[1] and Massimo Tavoni[1]

[1]FEEM/CMCC

ZEW Energy Efficiency Gap, March 13-14 2014

Energy efficiency in integrated assessment models

Assumptions about energy efficiency improvement (automonous and policy induced) play a key role in IAM scenarios:

Energy efficiency in integrated assessment models

Assumptions about energy efficiency improvement (automonous and policy induced) play a key role in IAM scenarios:

Role

- Major determinant of future energy and emissions
- Major mitigation option in the short run
- Considered to be cost effective
- Provides co-benefits

Energy efficiency in integrated assessment models

Assumptions about energy efficiency improvement (automonous and policy induced) play a key role in IAM scenarios:

Role

- Major determinant of future energy and emissions
- Major mitigation option in the short run
- Considered to be cost effective
- Provides co-benefits

Challenges

- Difficult to calibrate AEEI
- Criticism for being optmistic (SRES)
- Coarse sectoral and technology representation
- Difficult to account for non price effects
- Limited heterogeneity

Questions for this review

Energy efficiency in IAMs:

1. How much it matters? i.e. for
    1. the climate
    2. climate policy effort
2. How is represented and calibrated ?
3. Can we do better?

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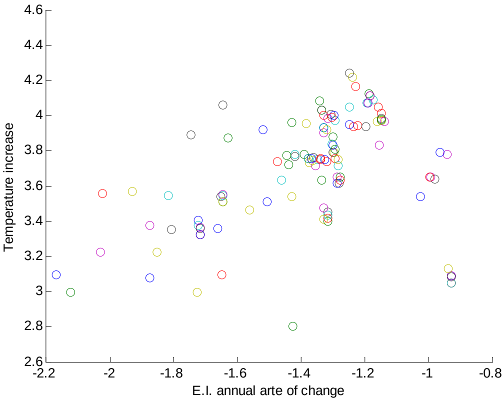
Energy efficiency in IAMs:

1. How much it matters? i.e. for
   1. the climate
   2. climate policy effort
2. How is represented and calibrated ?
3. Can we do better?

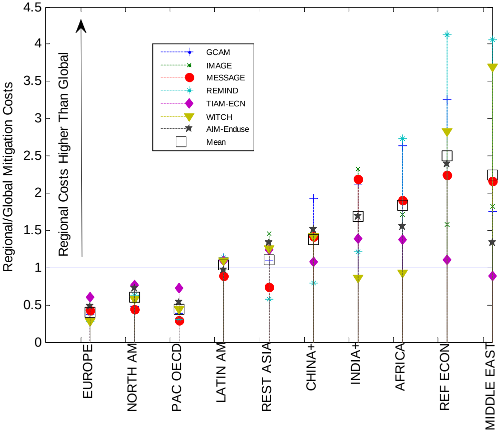
- outcome of large model comparison projects (MIPs) which fed into the upcoming IPCC 5th a.r. WGIII
- use Energy intensity as proxy

Energy Intensity and Climate Change



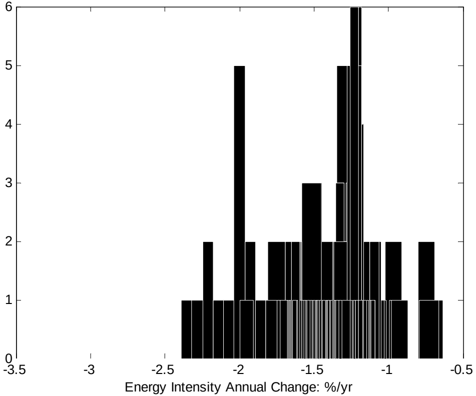
determinants of climate change: 1. income 2. energy intensity 3. population 4. carbon intensity of energy

Regional climate policy costs

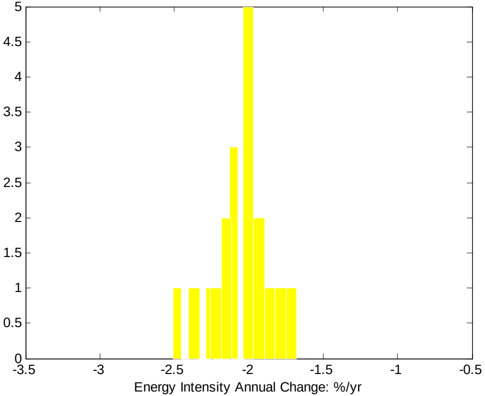


The most important driver of regional cost differences is energy/emission intensity in the BAU (Stern et. al 2012,Tavoni et al. 2014)

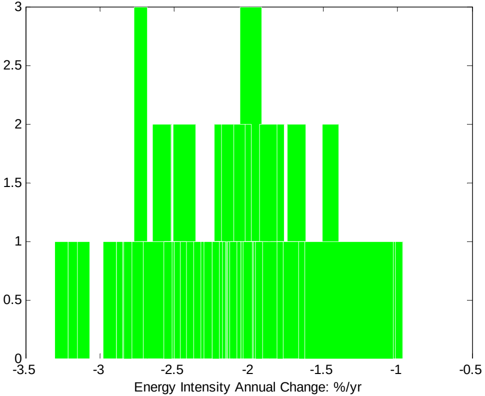
Future Energy Intensity distribution: BAU



Future Energy Intensity distribution: E.E. policies

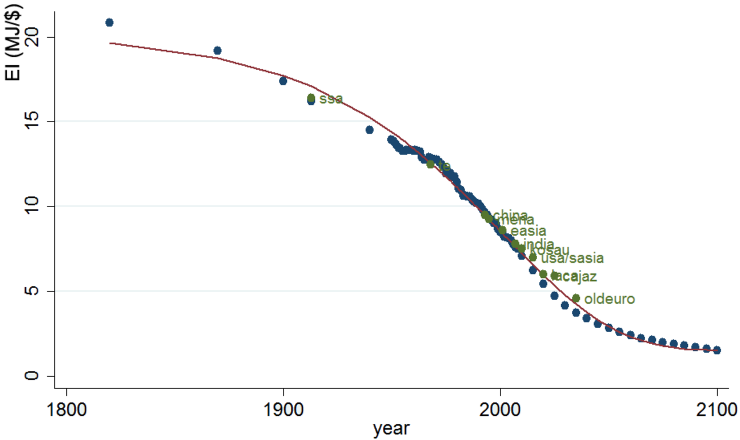


Future Energy Intensity distribution: climate policies

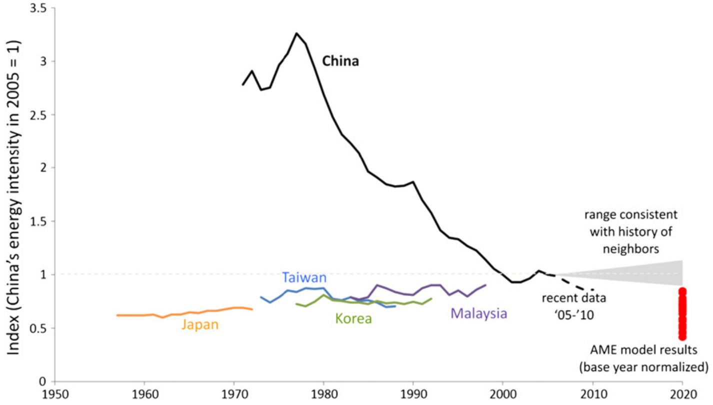


Asymptotic EI

- Historical Energy Efficiency - Gompertz Diffusion Model

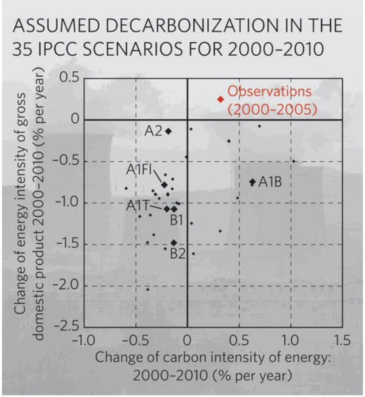


Too room for optimism?

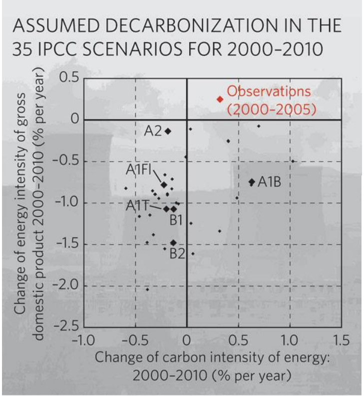


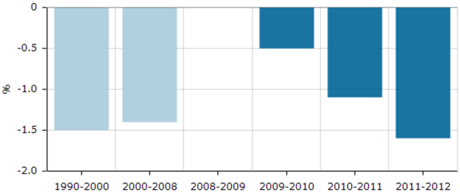
Blanford, Rose and Tavoni, 2013

IPCC SRES scenarios



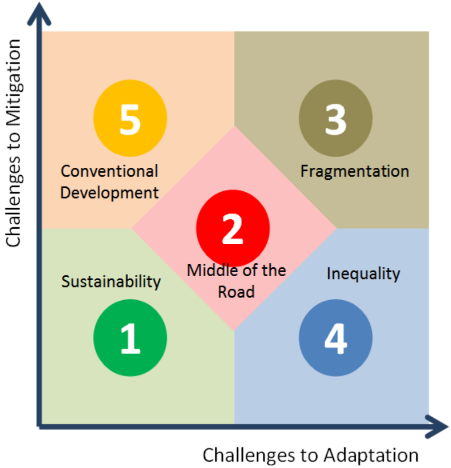
IPCC SRES scenarios





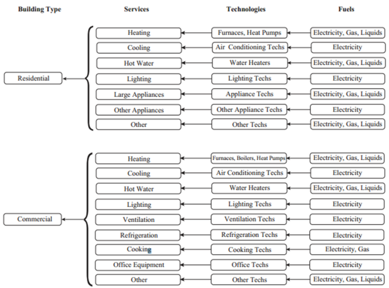
Shared Socio Economic Pathways

- Successors of SRES, to be published in 2014



Bottom up vs top down modeling

Figure 1: Schematic of the U.S. Buildings Sector in GCAM



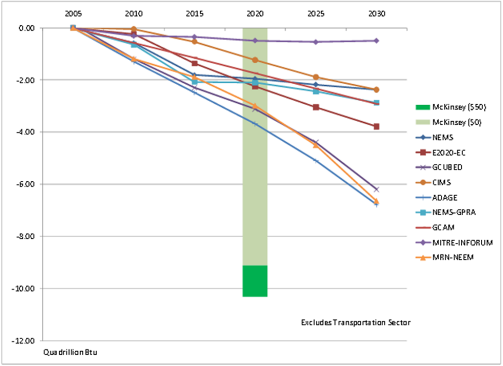
General equilibrium models are normally more aggregated

- CES production functions with energy as a factor of production
- Endogenous technical change via knowldge stock

controlled by elasticities and exogenous productivity changes

IAMs vs. Mckinsey

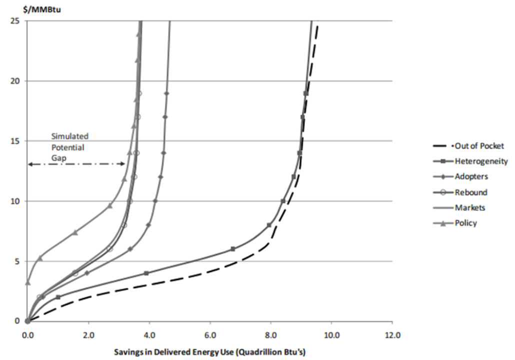
Figure 4. Energy Demand Reductions Achievable for Similar Carbon Prices



EMF25: Huntington et. al, 2012

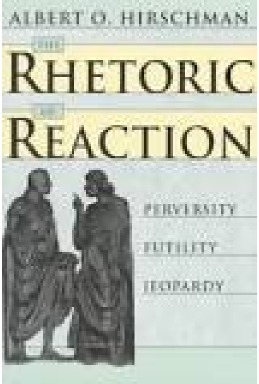
Efficiency Cost Curves (revisited)

Figure 3: Energy Efficiency Cost Curve After Adjustments (for 2020)



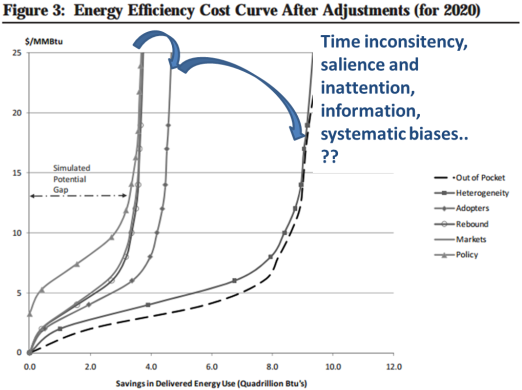
EMF25: Huntington et. al, 2012

Efficiency Cost Curves (revisited?)

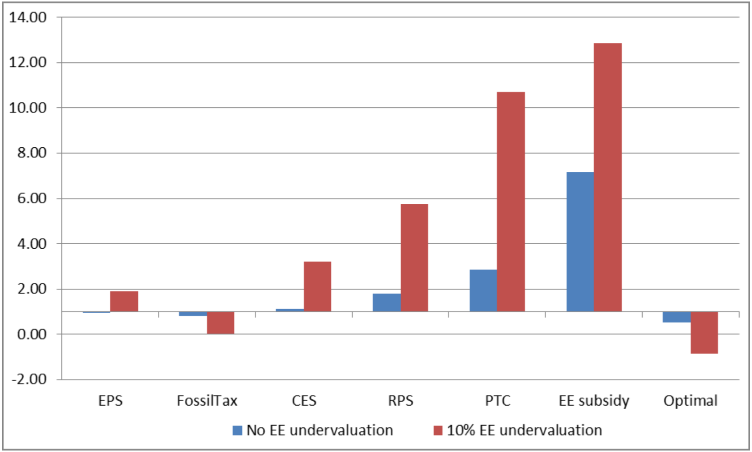


Futility	Rebound
Perversity	Heterogeneity
Joepardy	Costs

Efficiency Cost Curves (revisited again?)



Incorporating behaviour: undervaluation



Carolyn Fischer 2013 (work in progress)

Incorporating behaviour: the CIMS model

$$MS_j = \frac{\left[CC_j * \frac{r}{1-(1+r)^{-n_j}} + MC_j + EC_j + i_j \right]^{-v}}{\sum_{k=1}^{K} \left\{ \left[CC_k * \frac{r}{1-(1+r)^{-n_k}} + MC_k + EC_k + i_k \right]^{-v} \right\}}$$

CIMS model (Jaccard et. al)

Behavioural parameters: $i\,(intangible - costs)\,, v\,(heterogeneity)\,, r\,(risk)$

Incorporating behaviour: behavioural economics

quasi-hyperbolic discounting (Laibson)	$max_{EFF,ES_t} - c(EFF) + \lambda \sum_t \delta^t [b(ES_t) - (p_t + \tau_t) \cdot ES_t \cdot EFF]$
temptation (Gul and Peserdonfer)	$-c(EFF_H) + \delta [b(ES) - (p + \tau) \cdot ES \cdot EFF_H] - \lambda (c(EFF_H) - c(EFF_L))$
inattention (Chetty et al)	$U(\tilde{\xi}) = \lambda U(\xi)$
Social norms	$max_{ES} - c(ES_i) + b(ES_i) + \lambda \cdot n(ES_i, \bar{ES})$

Incorporating behaviour: behavioural economics

quasi-hyperbolic discounting (Laibson)	$max_{EFF,ES_t} - c(EFF) + \lambda \sum_t \delta^t [b(ES_t) - (p_t + \tau_t) \cdot ES_t \cdot EFF]$
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inattention (Chetty et al)	$\tilde{U(\xi)} = \lambda U(\xi)$
Social norms	$max_{ES} - c(ES_i) + b(ES_i) + \lambda \cdot n(ES_i, \bar{ES})$

Overarching questions:

1. Can we develop models with different resolution (i.e. behavioural) and link them (Rutherford decomposition algorithms)
2. Can-shall we use these for normative analysis, which is the main focus of IAMs ?

ERC Grant

New project starting (Politecnico di Milano, FEEM):

- behavioural motivations: RCT on residential energy use
- social networks: web/lab experiments on technology adoption and use
- modeling: better representation of energy demand

open to collaborations!

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Centre for Energy Policy and Economics
Department of Management, Technology and Economics

University of Surrey
SEEC Surrey Energy Economics Centre

University of Ljubljana
Faculty of Economics

Impact of Energy Policy Instruments on the Level of Energy Efficiency in the EU Residential Sector

Massimo Filippini, Lester Hunt, Jelena Zoric

Mannheim, 2014
ZEW

Outline

- **Motivation and goals of the paper**
- **Energy efficiency and productive efficiency**
- **Econometric analysis**
- **Conclusions**

A) Motivation and goals of the paper

- In the **new EU energy strategy** (Energy 2020) energy-efficiency is listed among the first 5 priorities: 20% energy savings to be achieved by 2020 (EC, 2010)

- Residential sector (30-40 % of the final energy consumption) is identified as being one of the areas **with the greatest potential for energy savings** (estimated to be 27%)

Motivation and goals of the paper

- In order to increase the level of energy efficiency it is important

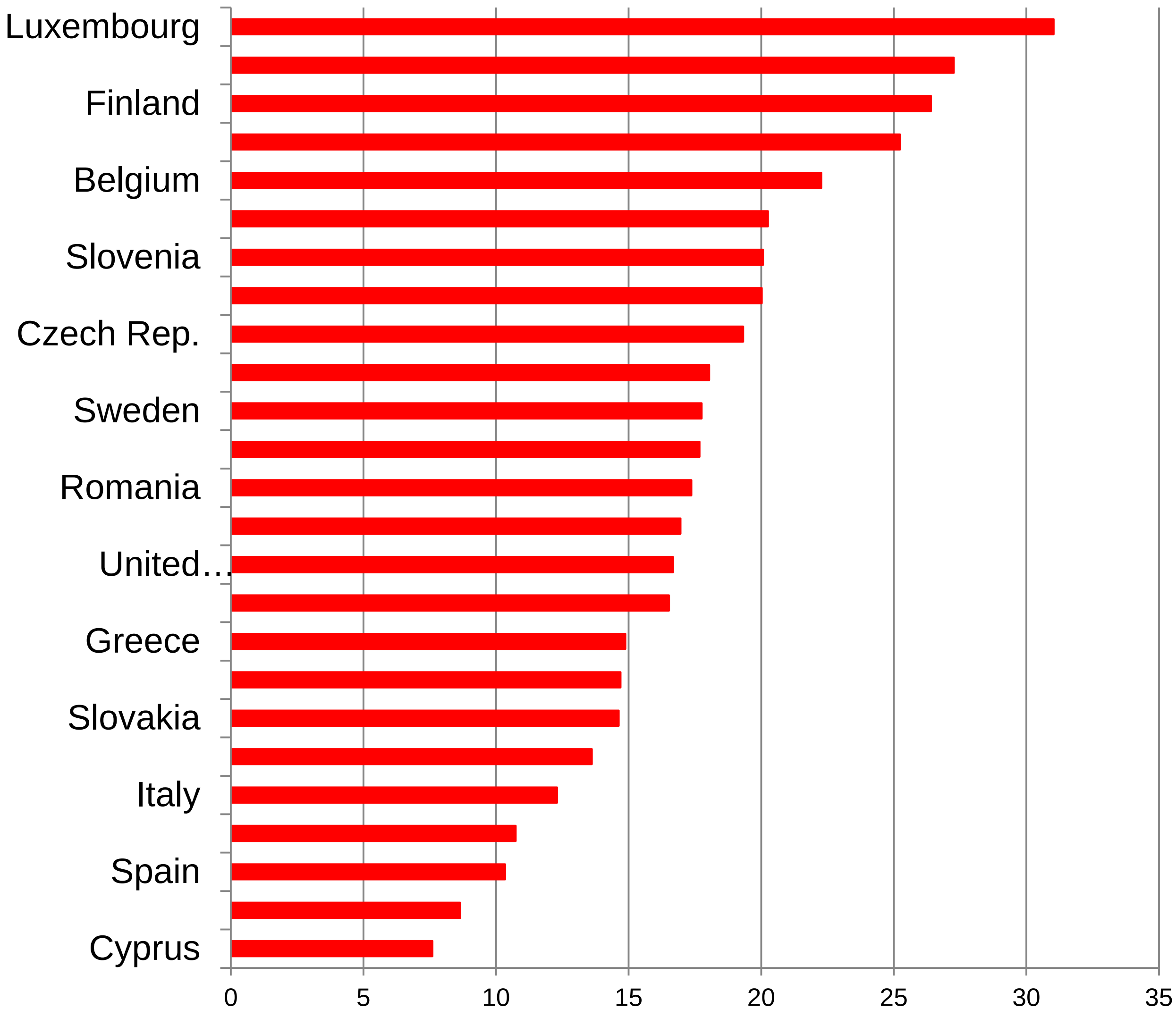
↪ to analyze the **impact of energy policy instruments on the level of energy efficiency**

↪ To **measure in a precise way** at the aggregate level (country or sector) **the level of energy efficiency** at the aggregate level (e.g. energy intensity is not a precise measure)

Measurement of energy efficiency using simple indicators

- Energy intensity (Energy consumption/GDP)
- Energy consumption per square meter
- Energy consumption per dwelling
-

Residential energy consumption per square meters



Weather
Income
Prices
Household size
…..
Level of efficiency

PROGRESS WITH IMPLEMENTING ENERGY EFFICIENCY POLICIES IN THE G8

INTERNATIONAL ENERGY AGENCY

"Energy intensity is commonly calculated as the ratio of energy use to GDP. Energy intensity is often taken as a proxy for energy efficiency, although this **is not entirely accurate** since changes in **energy intensity are a function of changes in several factors** including the structure of the economy, climate,… and energy efficiency"

Goals

- **Methodological:**
  - ↳ To estimate the level of energy efficiency applying a relatively novel approach based on: 1. the microeconomics of production; 2. the use of econometric methods and stochastic frontier analysis for panel data (Filippini and Hunt (2011,2012)); 3. aggregate data

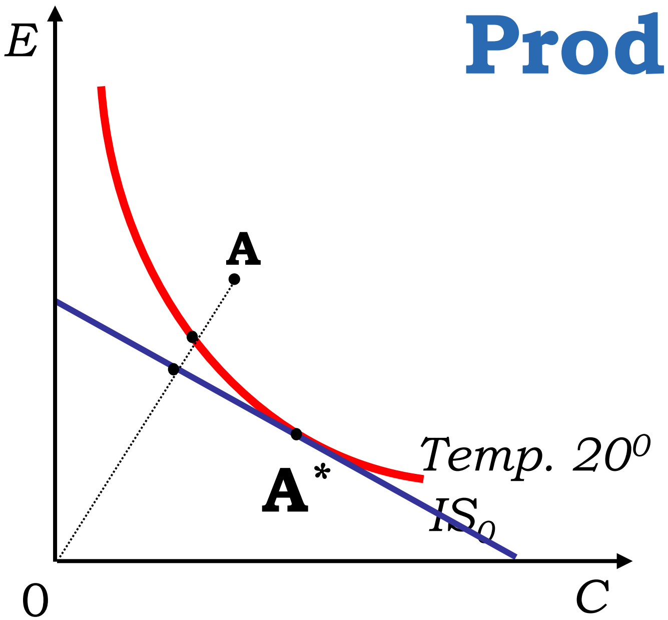
- **Policy-oriented:**
  - ↳ To analyze at the aggregate level the **impact of energy policy instruments** on the level of residential energy efficiency (EU states)

B) Energy-efficiency and productive efficiency

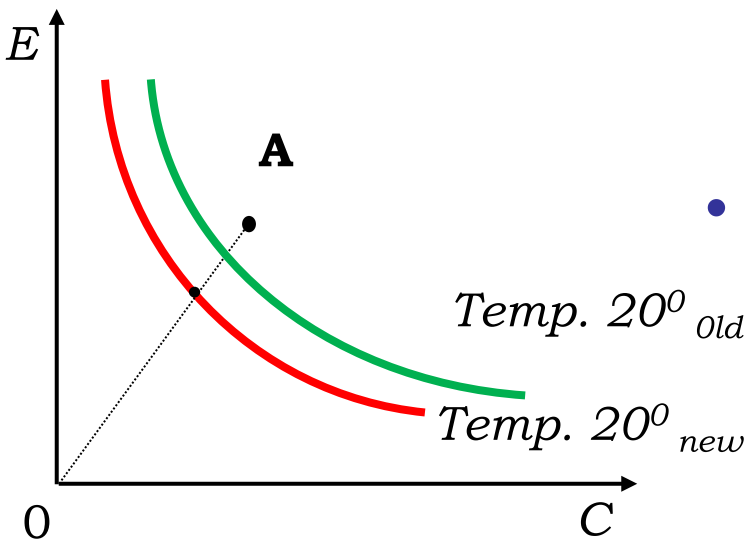
Energy Efficiency and productive efficiency

- Behind any **energy service** we have a **production process** and an associated **production function**.
- Use of capital, labor and energy
- From the microeconomics point of view the term energy efficiency is not precise
- Situation where the households are using in an inefficient way all inputs: related to the concept of productive efficiency (Farrell 1957)

Productive efficiency



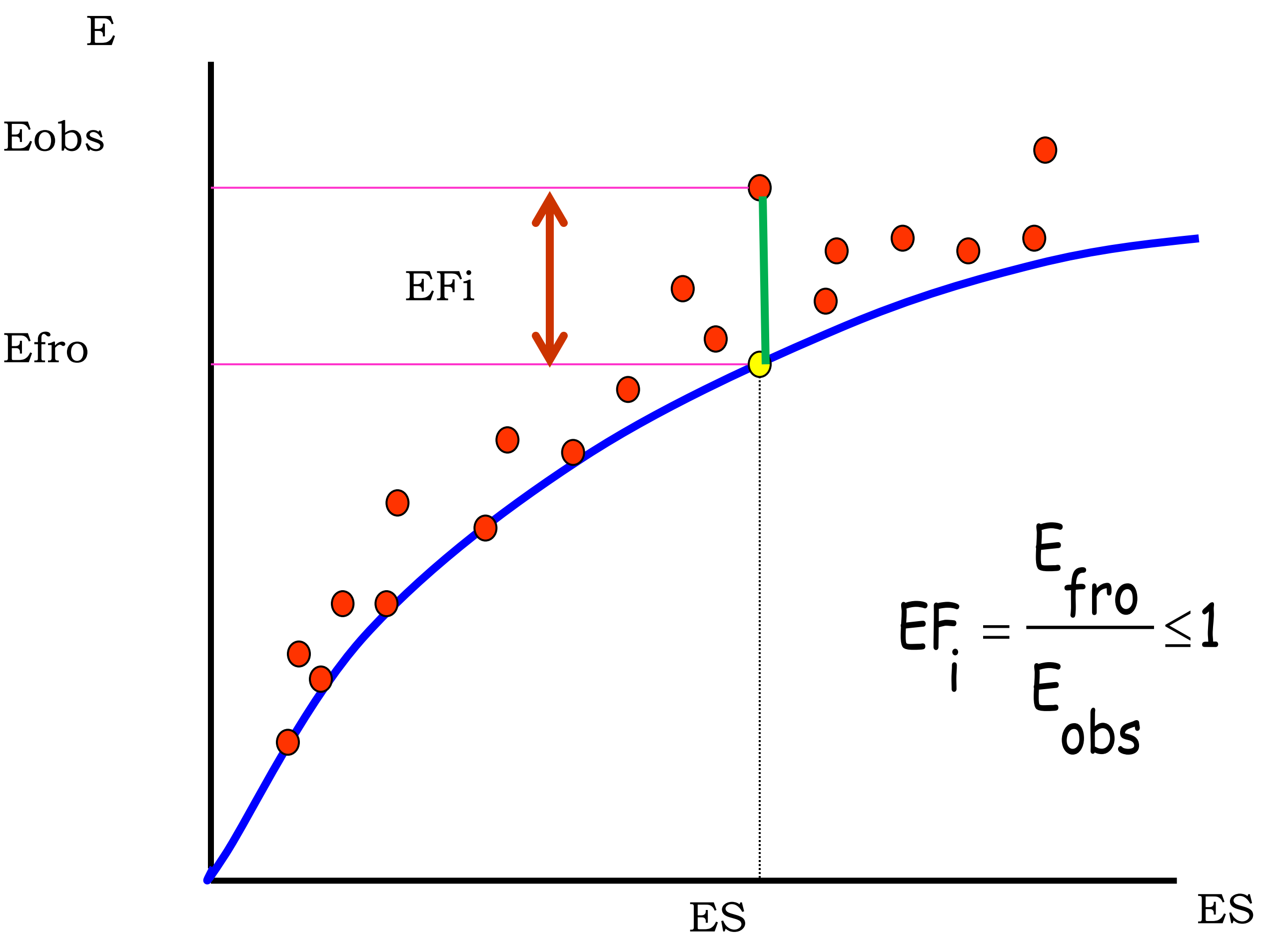
- Situation 1: An household is using in an inefficient way a technology ***A*** ➔ inefficient use of the inputs (capital and energy) to produce a room temperature of *20⁰*
  ➔ efficiency in **A** *



- Situation 2: An household is using an old technology ➔ inefficient use of the inputs (capital and energy)

An aggregate frontier energy demand model

simplified model E=f(Energy services)



$$EF_i = \frac{E_{fro}}{E_{obs}} \leq 1$$

Energy efficiency measures the ability of an household to minimize the energy consumption, given a level of an energy services

C) Model specification and econometric approaches

Empirical strategy

Estimation of an energy demand frontier function for the residential sector

Three econometric approaches (BC95, BC95 with Mundlak, TFE)

panel data set, 27 EU member states, 1996 to 2010

↓

Estimation for each country of an indicator of the level of energy efficiency for the residential sector

↓

Analysis of the impact of the energy policy measures on the level of energy efficiency

Residential energy demand model

$$ED_{it} = f\,(PE_{it}\,,\ Y_{it}\,,\ POP_{it}\,,\ DSIZE_{it}\,,\ HDD_{it}\,,\ HOT_i\,,\ T,\ EF_{it}\,)$$

ED_{it} represents the final residential energy consumption in country i in time t,

PE_{it} is the real energy price,

Y_{it} is the real income,

POP_{it} is population,

$DSIZE_{it}$ is the average size of a dwelling

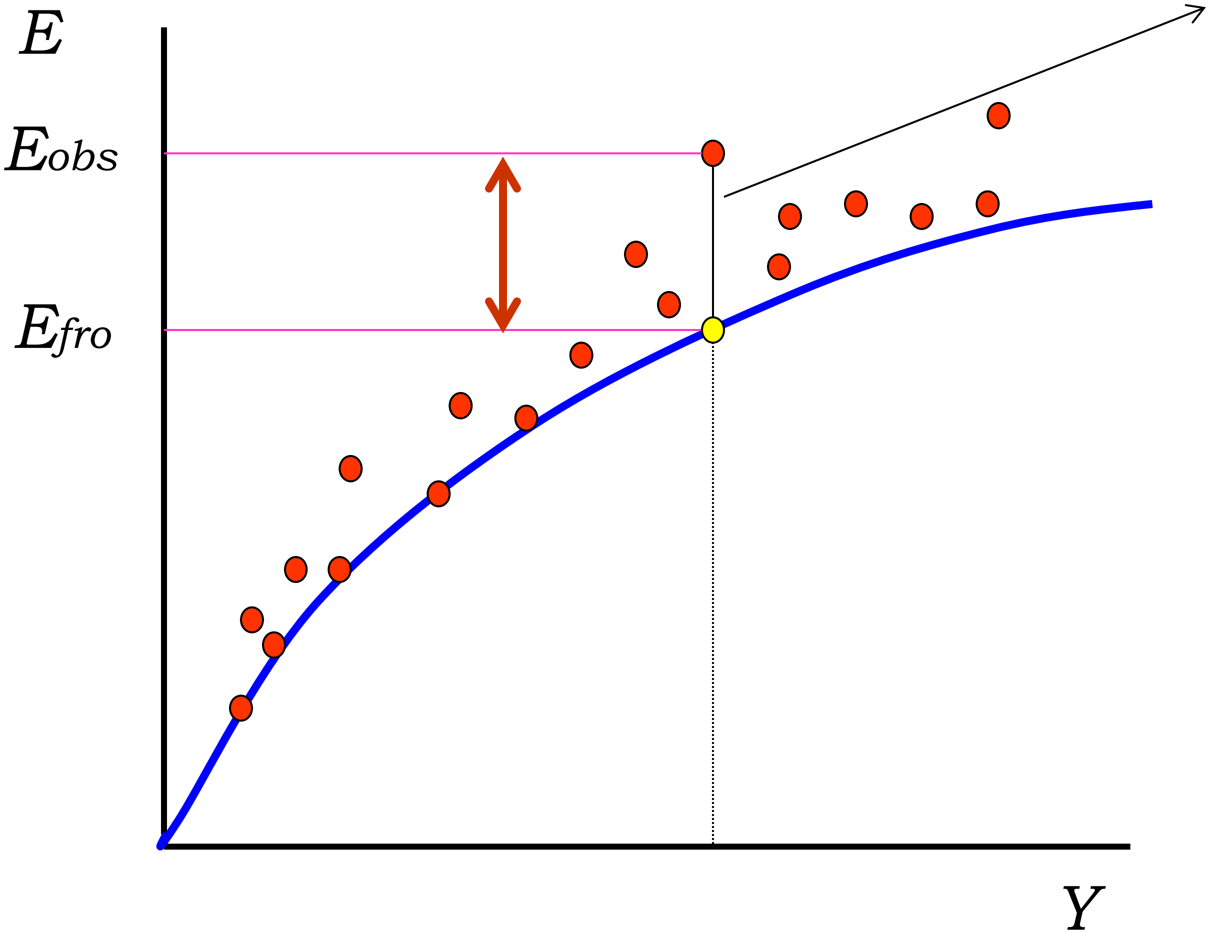
HDD_{it} heating degree days

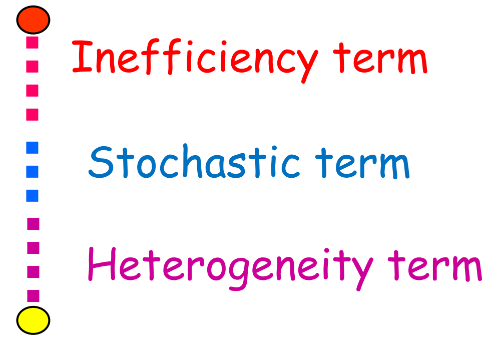
HOT_i is a dummy variable denoting hot climate,

T is a time variable for technical change.

EF_{it} level of 'underlying energy efficiency' of the EU residential sector.

Frontier energy demand model





Energy efficiency:
measures the ability of a state to minimize the energy consumption, given a level of Y

$$EF_i = \frac{E_{Frontier}}{E_{Observed}} \leq 1$$

Econometric model

$$Ln\, e_{it} = \alpha_i + \alpha_y\, lny_{it} + u_{it} + v_{it} \qquad u_{it} \geq 0$$

Individual Heterogeneity Mundlak

$$\alpha_i = \alpha_{\bar{y}}\, ln\bar{y}_{it} + \gamma_i$$

u_{it} is interpreted as an indicator of energy efficiency and is assumed to be half-normal distributed
Time varying inefficiency

v_{it}: a symmetric disturbance capturing the effect of noise and as usual is assumed to be normally distributed

Evaluation of the effectiveness of introduced EE policy measures

$$u_{it} = \eta' \mathbf{z}_{it} + e_{it}$$

:

- Energy performance standards
- Labelling schemes
- Information/Education campaigns
- Financial incentives and fiscal measures

D) Results

Member states and estimated average energy efficiency

Energy efficiency score (EFBCM)	Group	Member states
Below 86%	***Inefficient states***	BE, CY, DE, DK, EE, FI, GR, HU, IT, LV, PT
From 86% to 93%	***Moderately efficient states***	AT, FR, LU, PL, RO, SE, SI, SK
Above 93%	***Efficient states***	BG, CZ, ES, IE, LT, NL, UK

The efficiency estimates are found to be very poorly correlated (-0.07) with energy intensity (*EI*),

Impact of the energy policy instruments on the level of efficiency

- The results show that

↪ **financial incentives seem to have an important influence** on reducing energy inefficiency of the residential sector (financial dummies *FIN1* and *FIN2* highly significant)

↪ There is also some evidence that performance standards of buildings, heating systems and appliances contribute to improved efficiency (standard dummies significant only at 10%)

↪ similar results obtained by Bigano et al. (2011) using another approach

E) Conclusions

- EU residential sector holds a relatively high potential for energy savings

- A fair degree of variation among the EU member states in estimated energy efficiency levels is established

- Energy intensity indicator cannot be considered as a good proxy for energy efficiency and should be combined with other indicators in order to derive relevant policy conclusions

E) Conclusions

- Improved energy efficiency can be linked to

↳ the introduced financial incentives and energy performance standards

↳ Less evidence of an impact of the effect of informative measures such as labelling and educational campaigns

THANK YOU

FOR YOUR INTEREST

Energy-efficiency (EE) policy measures in the EU

	Measure type	Share in %
1	**Legislative/Normative**	**37.3**
1.1	Mandatory standards for buildings	15.0
1.2	Regulation for heating and hot water systems	15.6
1.3	Other regulation in the field of buildings	2.3
1.4	Mandatory standards for electrical appliances	4.4
2	**Legislative/Informative - labelling**	**15.2**
3	**Information/education**	**13.1**
4	**Financial**	**31.3**
4.1	Financial - grants, subsidies	26.3
4.2	Financial - loans, other	2.3
4.3	Financial - Tax Exemption/Reduction	2.6
6	**Others measures**	3.1
	Total	**100.0**

Source: Mure II database

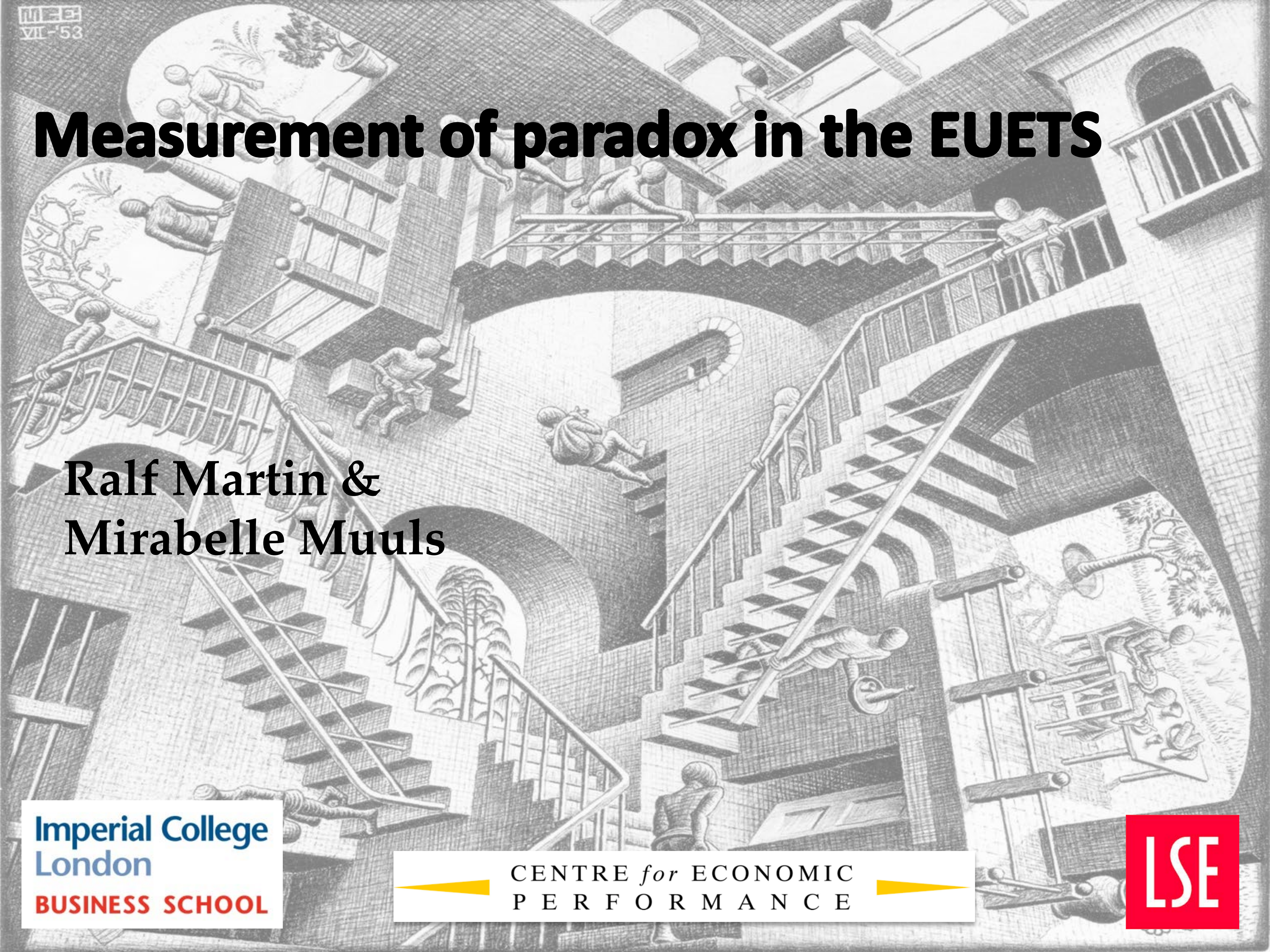
Table 1: Adopted energy-efficiency policy measures in the EU countries

Member state (MS)	Number of adopted policy measures by measure type					
	Legislative/ Normative	Legislative/ Informative - Labelling	Information/ Education	Financial/ Fiscal	Other	Total
Austria	7	2	6	7	1	23
Belgium	9	6	6	16	0	37
Finland	8	6	10	7	1	32
France	15	8	5	24	1	53
Germany	18	12	4	7	4	45
Greece	11	6	3	13	2	35
Italy	17	10	2	5	0	34
Spain	42	9	6	25	3	85
Sweden	4	7	4	6	2	23
United Kingdom	25	3	10	15	2	55
Total	**302**	**123**	**106**	**253**	**25**	**809**

Source: MURE II database.

Measurement of paradox in the EUETS

Ralf Martin &
Mirabelle Muuls



Imperial College London
BUSINESS SCHOOL

CENTRE for ECONOMIC PERFORMANCE

LSE

Motivation

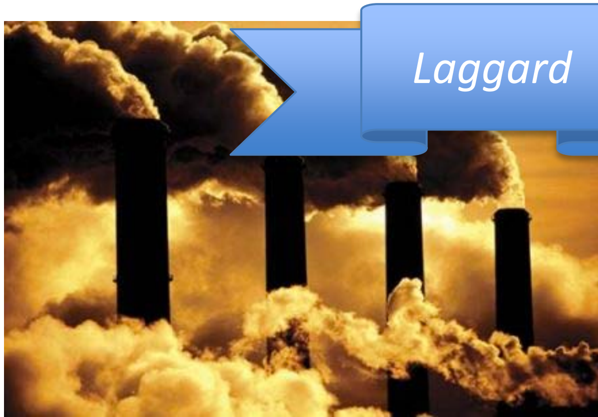
- Concerns that there is an energy efficiency paradox or gap
- Or perhaps not? Maybe costs and benefits are wrong in bottom up paradox calculations?
- Actual performance data should give us a better idea → Benchmarking

Benchmarking & paradox

- Compare energy intensity of different firms
- Energy (Expenditure) per
  - Output
  - Revenue
  - Employee
- Measures of paradox:
  - Spread of energy intensity
  - Counterfactual improvement:

Leader

Laggard



Source of performance data

- Government business census data
- Commercial balance sheet data

Two tales of high energy intensity

1. Low economic efficiency (MFP)

2. High economic efficiency is associated with energy intensive technology

Two tales of low energy intensity

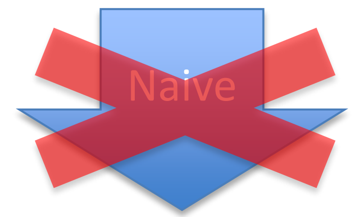
	Productivity	
Energy Intensity	High, Low	~~High, High~~
	~~Low, Low~~	Low, High

Not a paradox

Not a problem from an environmental point of view

Measurement of paradox

	Productivity	
Energy Intensity	High, Low	High, High
	Low, Low	Low, High



Energy paradox and climate policy

- Interesting for policy makers: win win potential
- Various existing policies focus explicitly on this; e.g.:
  - UK Carbon Trust, French ADEME: Advice businesses on how to reduce costs and energy consumption
  - UK Carbon Reduction Commitment (CRC): benchmarking exercise with financial transfers from laggards to leaders (at least initially)
  - EU ETS: Permit allocation on the basis of performance benchmarks.

To motivate and evaluate such policies, measurement of the severity of the energy paradox is key

Modeling firms

Firm specific TFP shifter

Cobb-Douglas production function with firm specific energy intensity

Log linear demand with firms specific demand shifter (quality, consumer valuation)

Production function estimation

Using demand function

$$r_{it} = q_{it} + p_{it} = \frac{1}{\mu}\left(q_{it} + \lambda_{it}\right)$$

Most datasets only have revenue data

Markup parameter μ=1/(1-1/η)

$$= \frac{\alpha_{Eit}}{\mu}\left(e_{it} - k_{it}\right) + \frac{\alpha_{Mit}}{\mu}\left(m_{it} - k_{it}\right) + \frac{\alpha_{Lit}}{\mu}\left(L_{it} - k_{it}\right) + \frac{\gamma}{\mu}k_{it} + \frac{1}{\mu}\omega_{it}$$

Using production function

Composite demand & technology shock a+λ

Regression equation

$$\chi_{it} = \frac{\gamma}{\mu} k_{it} + \frac{1}{\mu} \omega_{it}$$

Computable from data

$$\chi_{it} = r_{it} - s_{Eit}\left(e_{it} - k_{it}\right) - s_{Mit}\left(m_{it} - k_{it}\right) - s_{Lit}\left(L_{it} - k_{it}\right)$$

$$s_{Eit} = \frac{\alpha_{Eit}}{\mu} = \frac{E_{it} W_{Eit}}{R_{it}}$$

From short run profit maximisation

$$\omega_{it} = \rho \omega_{it-1} + \nu_{it}$$

Estimation of economic efficiency

$$\frac{\hat{\omega}_{it}}{\mu} = \chi_{it} - \frac{\hat{\gamma}}{\mu} k_{it}$$

Below we compute this holding parameters fixed at the 3 digit sector level

We compare the distribution of economic efficiency to the distribution of energy intensity at the sectoral level

$$s_{Eit} = \frac{\alpha_{Eit}}{\mu} = \frac{E_{it} W_{Eit}}{R_{it}}$$

Benchmarking

$$\overline{\ln \frac{W_E E}{R}}^{Bench} = \frac{1}{N} \sum_{i \in TOP} \ln \frac{W_E E_i}{R_i}$$

Average energy intensity of firms with above median productivity and below median energy intensity

$$TOP = \left\{ i \in \frac{W_E E_i}{R_i} < \overline{\frac{W_E E}{R}}^{Median} \cap \omega_i > \overline{\omega}^{Median} \right\}$$

A measure of paradox

By how much does energy consumption reduce if below median productive and above median energy intensive firms had the energy intensity of the benchmark – ceteris paribus

$$REDUX = \frac{\sum_i \Delta^{CF} E_i}{\sum_i E_i}$$

$$\Delta^{CF} E_i = \begin{cases} \left[\exp\left(\overline{\ln \frac{W_E E}{R}}^{Bench} - \ln \frac{W_E E_i}{R_i} \right) - 1 \right] E_i & \text{if } i \in BOT \\ E_i & \text{otherwise} \end{cases}$$

Data

- Production data for French manufacturing firms: Enquete Annuelle des Entreprise (EAE) & Enquete Annuelle sur les Consommations d'Energie dans l'Industrie (EACEI)

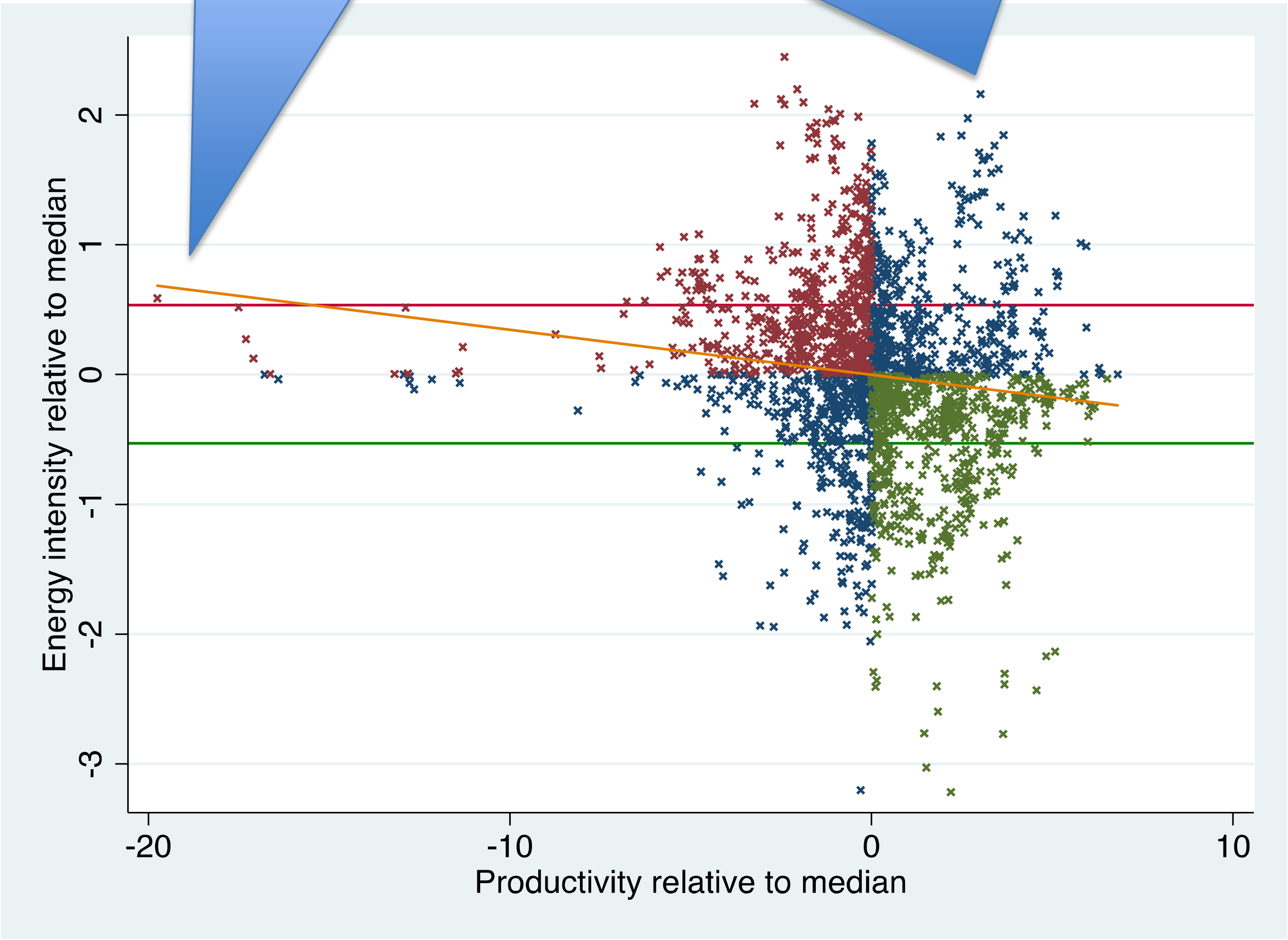
- We focus (initially) on firms regulated by the EU ETS
  - Gives an idea of the relevance of benchmarking within the ETS
  - Ensures we are dealing with comparable firms

- Unbalanced sample of ~300 firms, 1996-2007

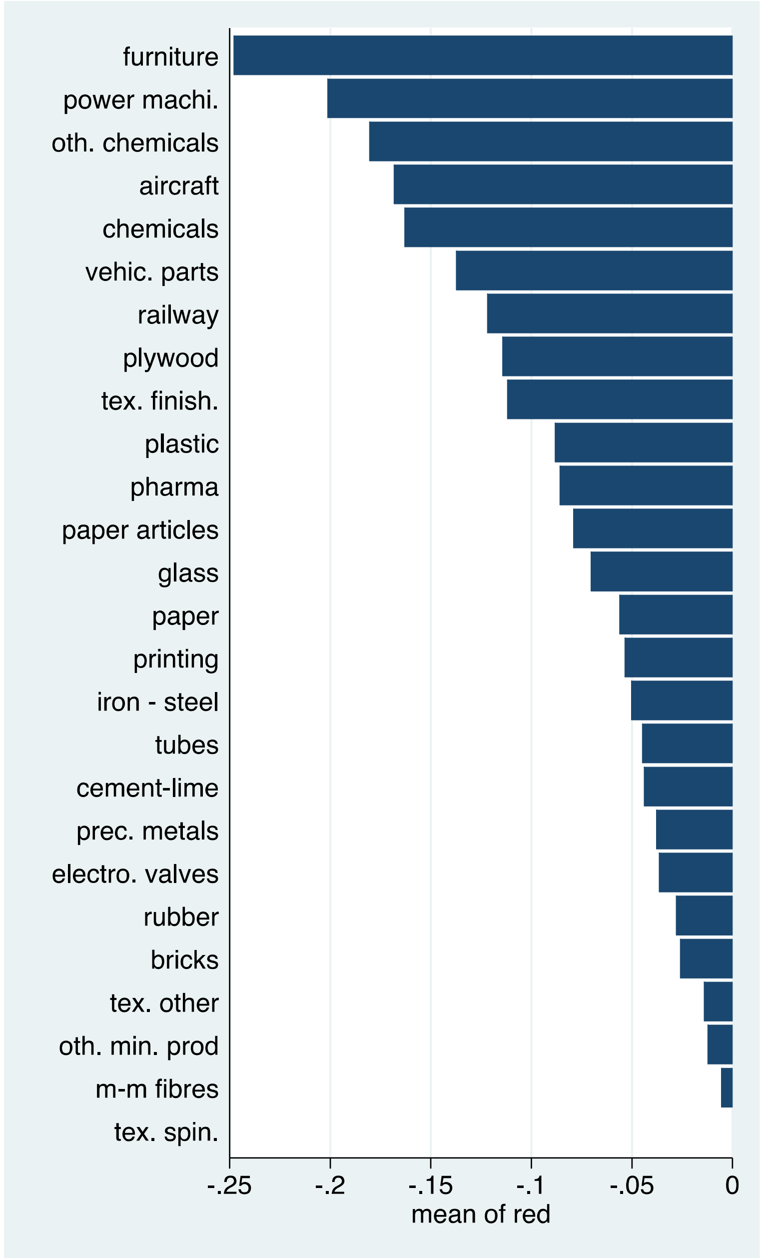
Energy intensity vs. productivity

Negative correlation

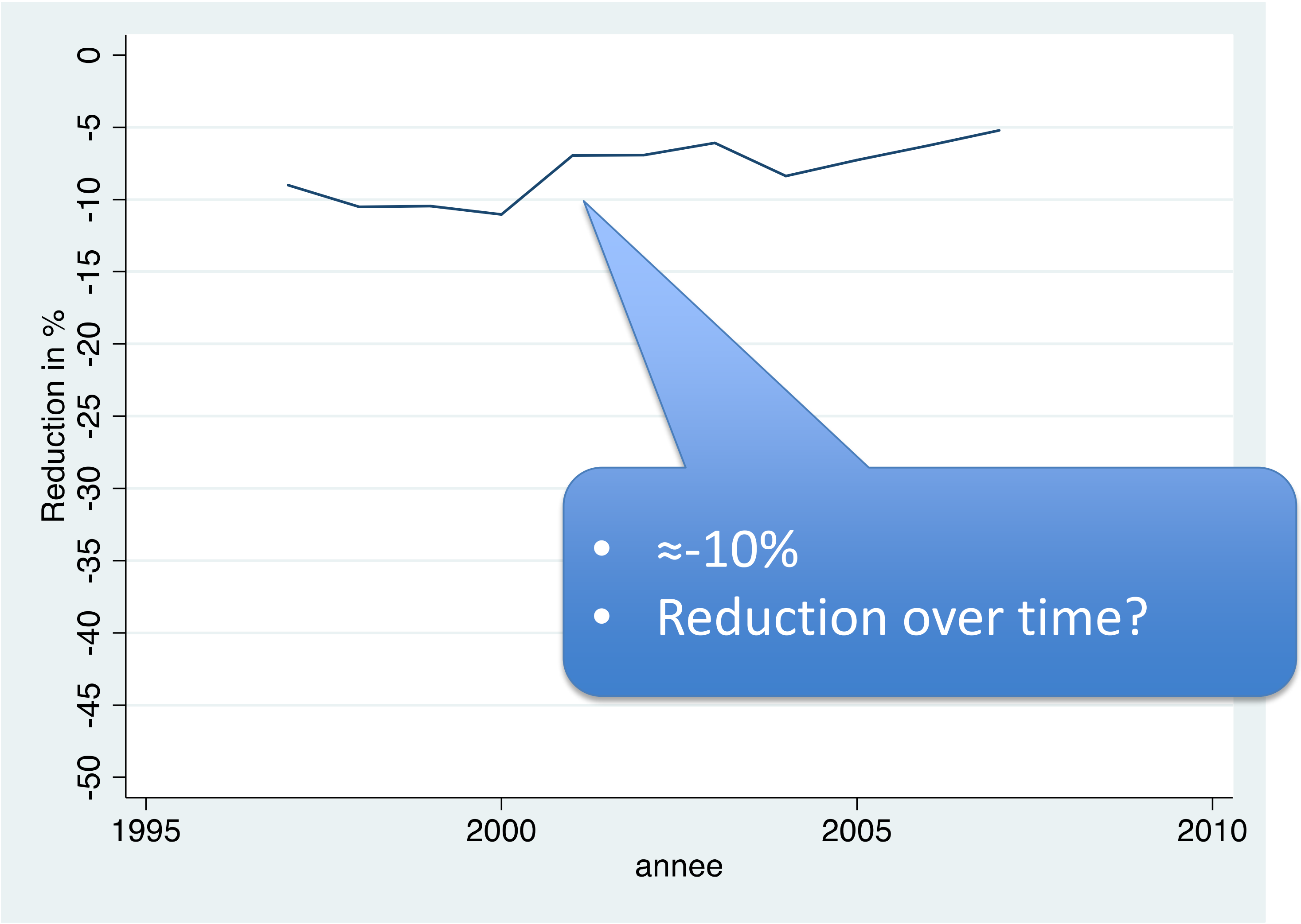
High productivity & energy intensity firms



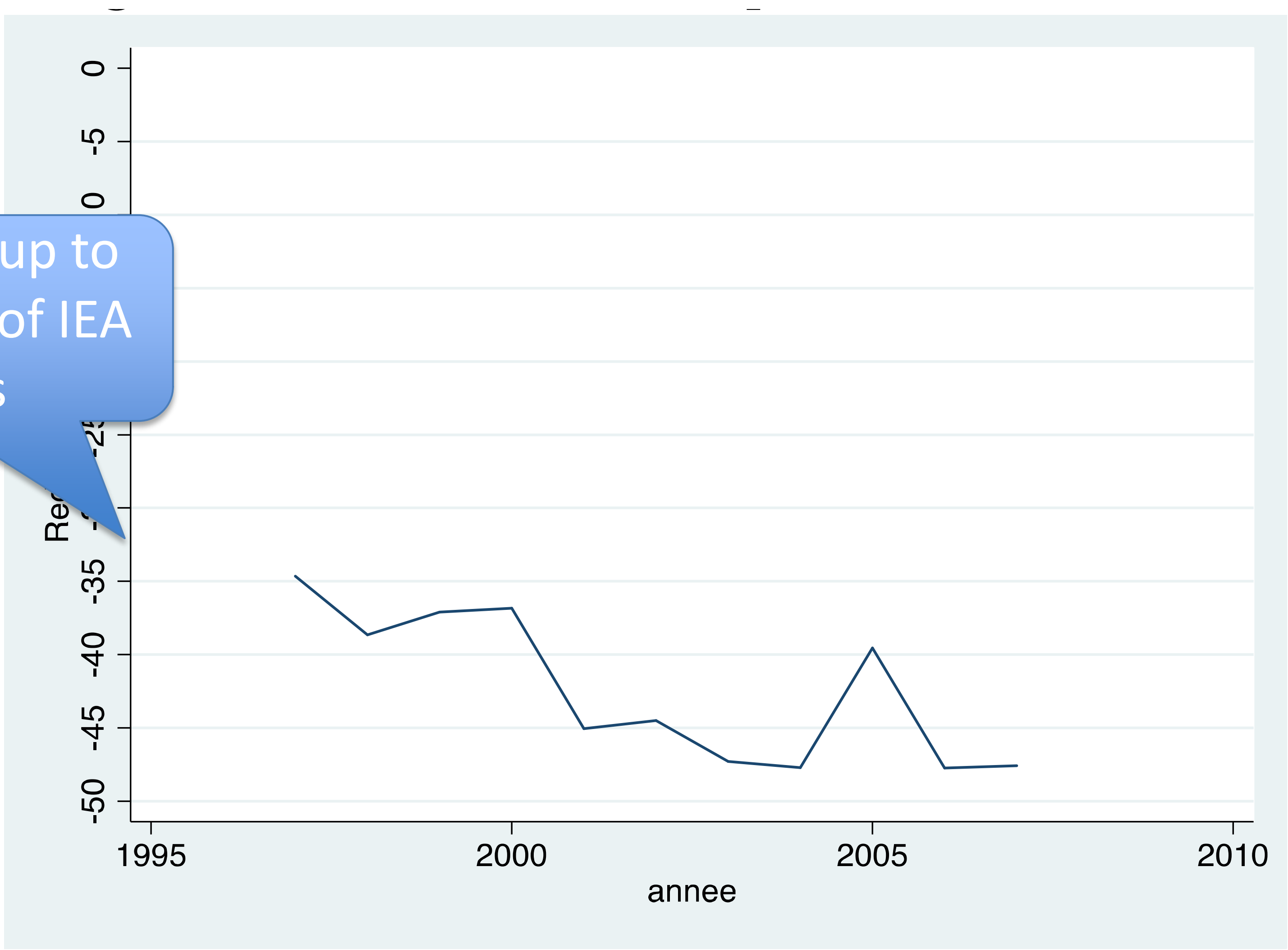
Reduction potential across sectors



Aggregate Reduction potential over time

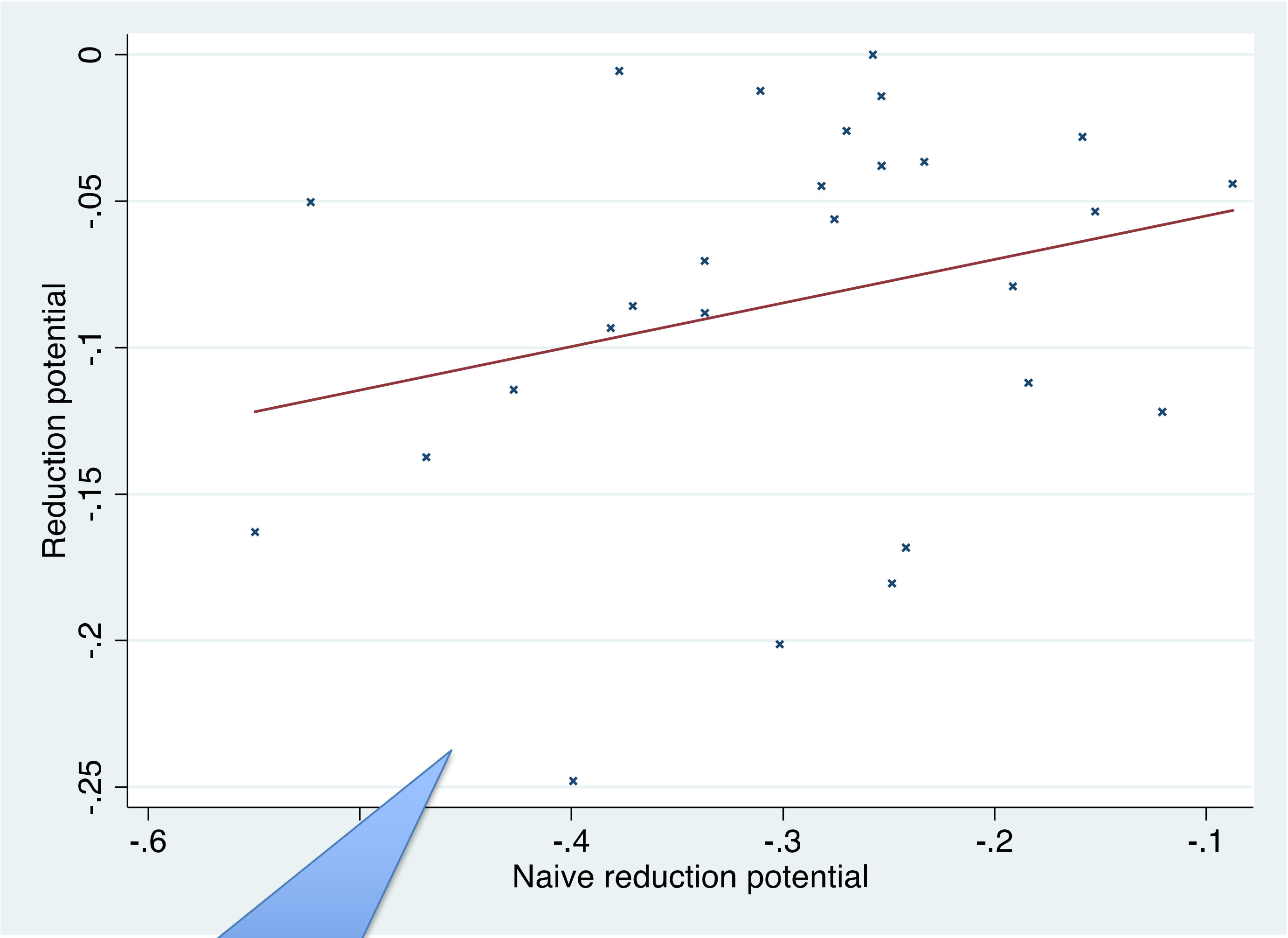


Naïve reduction potential



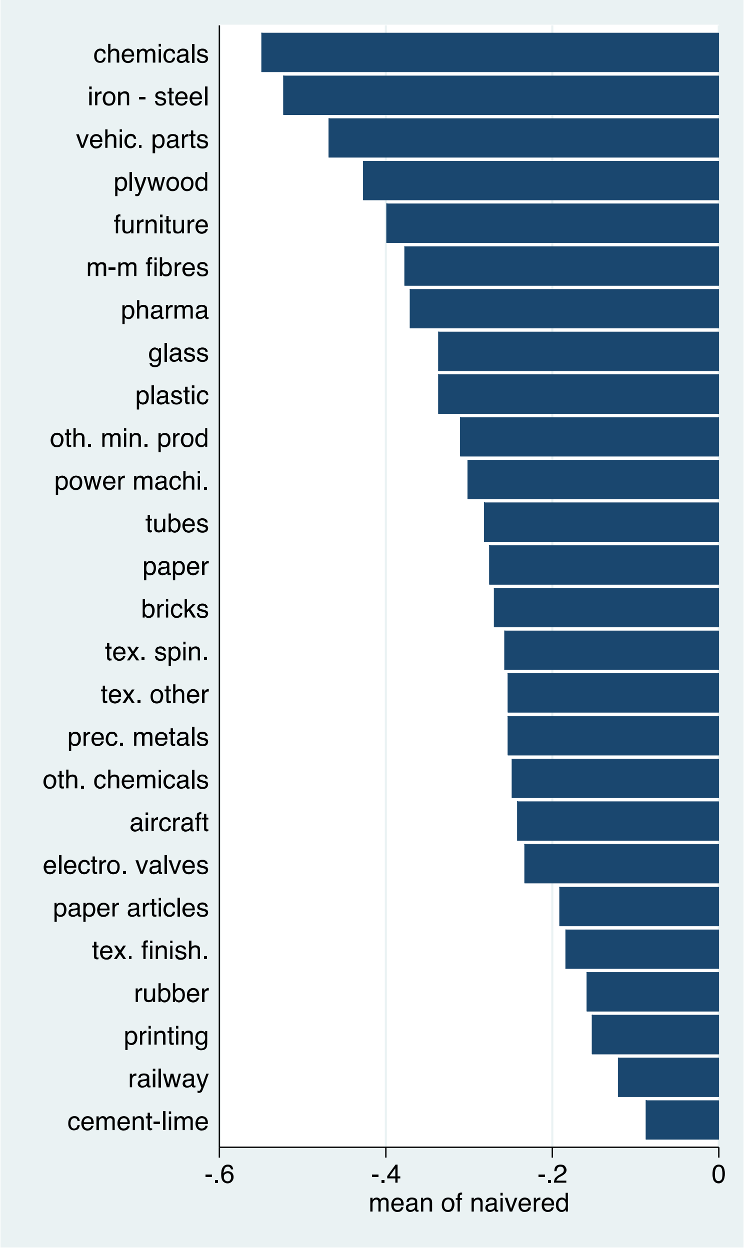
Vastly higher: up to 50% but short of IEA estimates

Naïve vs sophisticated across sectors



Positive Correlated but ranking not preserved

Naïve potential across sectors



Between -60% and -10%

Conclusion

- New approach to measure energy gap from common firm level data
- Suggests there is a reduction potential of about 10% within ETS manufacturing firms
- Wide variation between sectors (0 to 25%)
- Naïve approach would yield vastly larger estimates and different ranking of industries

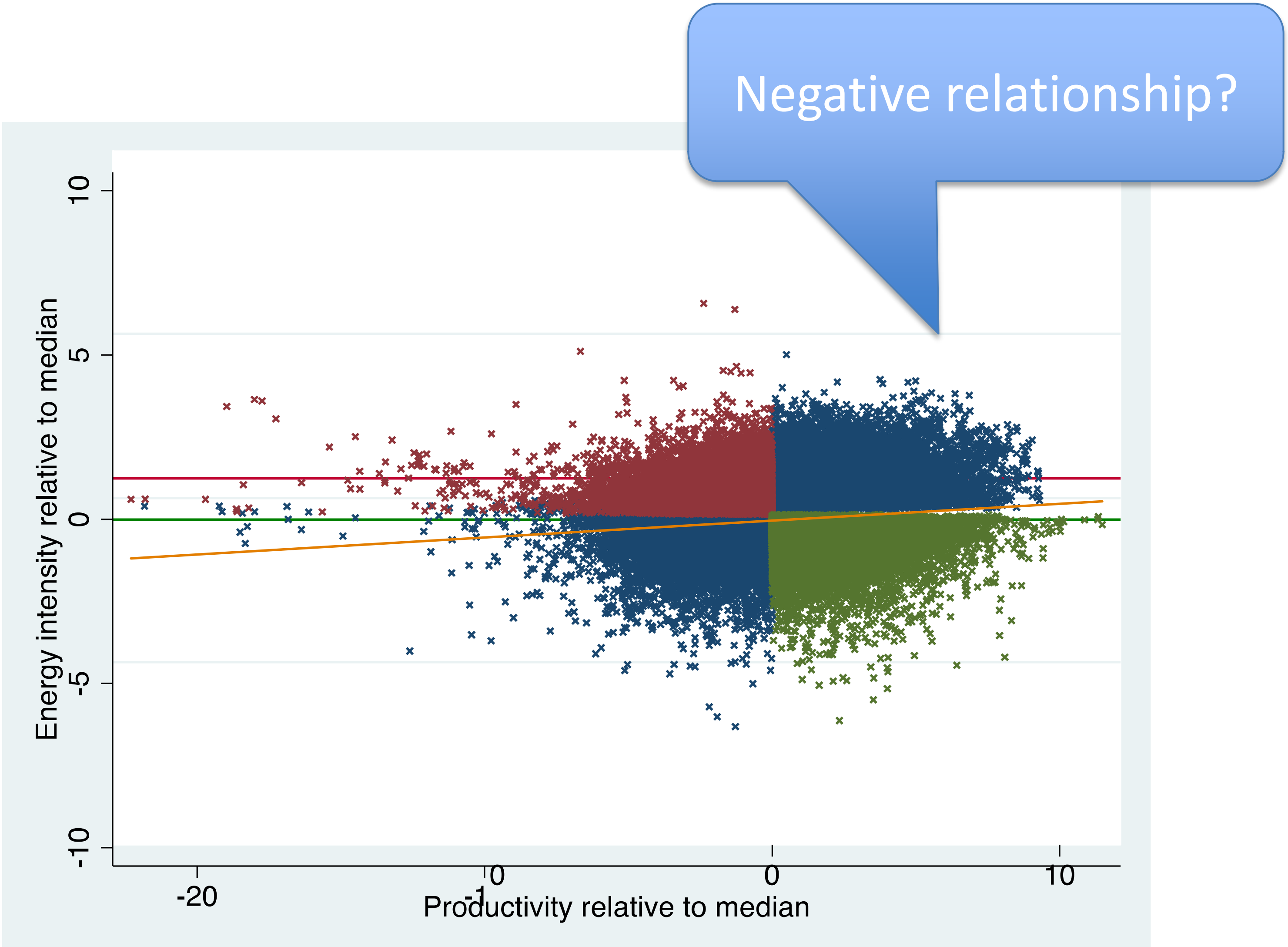
The road ahead

- Compute for more datasets, samples & policies
- Compute benchmark and counterfactual in alternative ways
- More sophisticated model of firms; e.g.
  - Allowing for firm specific variations in market power
  - Allow for capital stock age, vintages
  - Size/Rebound effects?
  - Market structure?

Thanks – r.martin@imperial.ac.uk

Extra slides……

All ETS & non ETS firms



All ETS & non ETS firms – Reduction potential

Effect much lower