

Energy Efficiency

Part 1: EE Gap Model + Nudges

Prof. Richard Sweeney

ECON3391.01, Boston College

- Module: Discuss what energy efficiency means in *economic* terms, and why it's so popular in policy circles
- Today: Go through Allcott & Greenstone model of EE and behavioral explanations for the energy efficiency gap
- Next class: Discuss rational explanations and nudges
- Next week: Measuring EE policy benefits

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Americans spend a lot of money on energy

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Summary

In 2023, [BLS Consumer Expenditure Survey](#) reports that the average US household spent:

- \$2,694 on gasoline
- \$1,762 on electricity
- \$540 on natural gas
- \$140 on fuel oil

Americans spend a lot of money on energy

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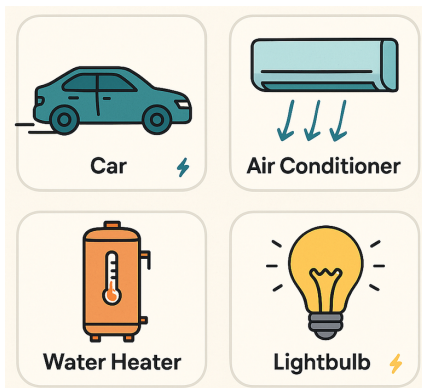
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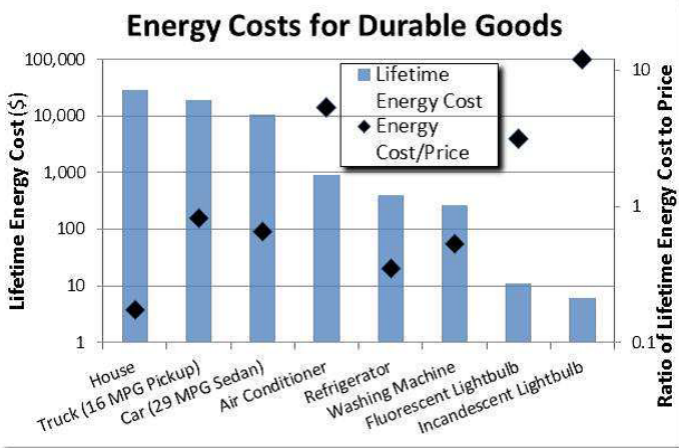
Important: We don't get any utility from energy directly.

Actual utility comes from energy “services” generated
when combined with other capital



What matters for utility is the *total* cost of energy services:
capital costs + energy costs

The ratio of energy costs to capital costs varies a lot



Source: Allcott & Greenstone (2012)

Many policies in place to encourage the adoption of more efficient energy-using capital

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Policy	Years	Magnitude
<u>Standards</u>		
Appliance efficiency standards	1988-	\$2.9 billion annual cost
Building codes	1978-	
CAFE standards	1978-	\$10 billion annual cost
<u>Prices</u>		
Federal Hybrid Vehicle Tax Credit	2006-2010	\$426 million annual credit
Gas guzzler tax	1980-	\$200 million annual revenues
Weatherization Assistance Program	1976-	\$250 million annual cost
Demand-Side Management	1978-	\$3.6 billion annual cost
2009 Economic Stimulus	2009-	\$17 billion total
<u>Information and Marketing</u>		
Fuel economy labels	mid-1970s	
Appliance "yellow tags"	1980	
Energy Star program	1992	\$50 million annual cost

Source: Allcott (2015)

Energy efficiency vs. energy taxes

- Consider the market for oil.
- CO2 emissions contribute to climate change.
- Two ways to reduce oil consumption:
 - Tax oil → increase price p
 - Make cars more energy efficient (increase fuel economy)
 - This reduces the quantity demanded at every price

One of the reasons EE is so popular is that people believe it's a "win-win" proposition

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This sentiment has been popular for four decades now (Lovins 1979, McKinsey & Co. 2009)

Win #1: Energy consumption is associated with many externalities

- reducing energy use brings us closer to the social optimum
- this seems pretty clear

One of the reasons EE is so popular is that people believe it's a "win-win" proposition

This sentiment has been popular for four decades now (Lovins 1979, McKinsey & Co. 2009)

Win #1: Energy consumption is associated with many externalities

- reducing energy use brings us closer to the social optimum
- this seems pretty clear

Win #2: Consumers fail to take up **privately** optimal EE investments

- for example because they do not have correct information
- correcting this mistake saves them money
- much less obvious (to economists)



JOSEPH R. BIDEN

46th President of the United States: 2021 - present

FACT SHEET: Biden-Harris Administration Takes More Than 100 Actions in 2022 to Strengthen Energy Efficiency Standards and Save Families

Money

December 19, 2022

Department of Energy Proposes New Lightbulb Efficiency Rule

Today, the White House and the Department of Energy (DOE) announced that the Biden-Harris Administration has [surpassed its goal](#) to take 100 actions in 2022 to strengthen energy efficiency standards for a range of appliances and equipment to lower costs for American families. These new standards advanced by the Biden-Harris Administration will help save the average family at least \$100 annually through lower energy bills.

Model

A model of energy efficiency

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Total cost (TC) of energy using capital:

$$\underbrace{TC}_{\text{total cost}} = \underbrace{c}_{\text{capital cost}} + \underbrace{epm/(1+r)}_{\text{energy cost}}$$

- c is the **up-front** cost of capital

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- m is the amount the good is used (ie miles driven)
- p is the price of energy
- e is **energy efficiency** (energy use per unit of use m)

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- m is the amount the good is used (ie miles driven)
- p is the price of energy
- e is **energy efficiency** (energy use per unit of use m)
- **A key feature of this problem is that capital costs are up front, but energy costs are incurred in the future.**
 - For simplicity, assume all energy expenditure occurs in a single “future” time period.
 - r is the rate of time preference (discount rate) between utility now and utility in the future.

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Example: 2022 Toyota RAV4

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Imagine two identical goods, that differ only on energy use and up-front cost.

Toyota RAV4 vs. RAV4 Hybrid: Which Should You Buy?

Find out how the two Toyota SUVs stack up.

Motor Trend Staff - Photos; Kelly Lin - Words | May 4, 2020



- Fuel economy (e): 27 vs 41 MPG (city)
- Up front cost (c): \$26,975 vs \$29,575

For otherwise identical products, consumers should minimize total costs

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Summary

- Two goods: inefficient ($j = I$); efficient ($j = E$)
 - Efficient good cost more today: $c_E - c_I > 0$
 - But saves on energy tomorrow: $e_E - e_I < 0$
- Total cost of good j

$$TC_j = c_j + e_j pm / (1 + r)$$

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$$TC_j = c_j + e_j pm / (1 + r)$$

- purchase E if $TC_E < TC_I$
- implies:

$$c_E - c_I < \frac{(e_I - e_E)p}{(1 + r)} * m$$

Who should buy the efficient good?

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Energy expenditure on service:

$$\text{Expense} = \left(\frac{\text{energy}}{\text{usage}} \right) (\text{usage}) (\text{energy price}) (\text{discount factor})$$

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Who should buy the efficient good?

Energy expenditure on service:

$$\text{Expense} = \left(\frac{\text{energy}}{\text{usage}} \right) (\text{usage}) (\text{energy price}) (\text{discount factor})$$

Last three terms are **random variables** that vary across individuals (i)

$$\text{Expense}_i = (e) (m_i) (p_i) \left(\frac{1}{1 + r_i} \right)$$

Tracing out a demand curve for the efficient good

- Hold usage levels m_i fixed.
- Individual energy savings from buying efficient good E :

$$(e_I - e_E) \left(\frac{m_i p_i}{1 + r_i} \right)$$

- If we arrange everyone in descending order of this value, this traces out a **demand curve** for E (draw this)
- Assume everyone buys capital, they are just deciding between the inefficient good I and the efficient good E . Then the relevant “price” of E is the difference in upfront costs $(c_E - c_I)$.
- Everyone who saves more than this amount **should** buy E . Everyone who saves less should not.

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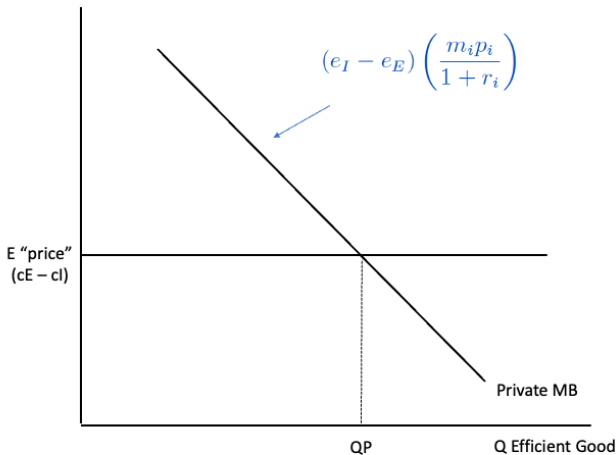
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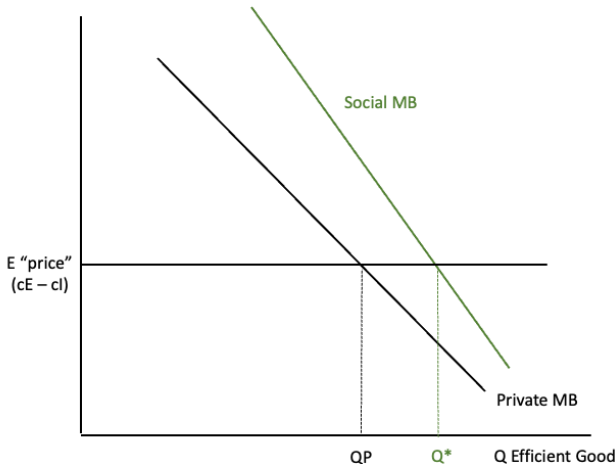
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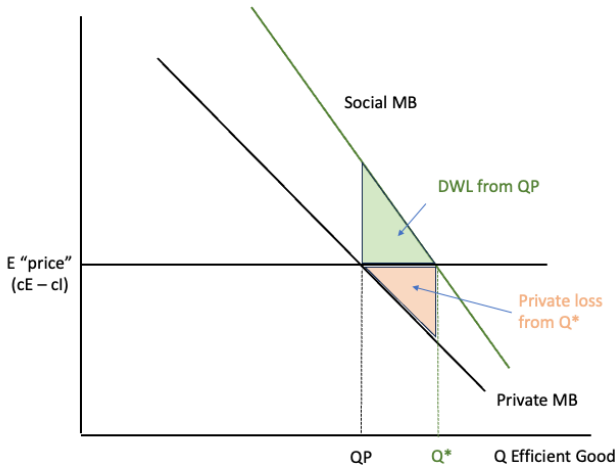
EE gap

We know that people use too much energy because of unpriced externalities

In the model, p should be $p_{social} = p + \phi$, where ϕ is the marginal external cost of energy use



In the rational model, consumers would lose money if they were more efficient. But society would gain.



The energy efficiency “gap” (or “energy paradox”)

- **Energy paradox** is the observation that energy-efficiency technologies that would *privately* pay off for adopters (in terms of energy cost savings) . . . are nevertheless not adopted
 - ie $TC_E < TC_I$, but consumers still chose I

The energy efficiency “gap” (or “energy paradox”)

- **Energy paradox** is the observation that energy-efficiency technologies that would *privately* pay off for adopters (in terms of energy cost savings) . . . are nevertheless not adopted
 - ie $TC_E < TC_I$, but consumers still chose I
- What are some possible reasons for this? Why might consumers choose I even if the energy savings outweigh the upfront cost?

$$c_E - c_I < \frac{(e_I - e_E)p}{(1 + r)} * m$$

Economics historically assumed that agents were infallible, computationally limitless and rational.

- implies people must be cost minimizing

In the real world, human beings:

- **make mistakes (misoptimize)**
- don't like thinking hard about things (there is a cost to optimization)
- **are inattentive**
- experience regret/ loss aversion
- care about peer effects
- are easily swayed by default options
- overly discount the future (present bias)

This is important for energy efficiency because it can

- explain the gap
- suggest ways to correct it that don't involve taxes/ regulation
 - (and cost much less)

Sometimes information is presented correctly, but consumers are just not attentive to it (or it isn't salient enough)

Example: Online shipping (Hossain & Morgan 2006)

- total cost of buying a something online = price of the good + shipping costs
- consumers should only care about the total cost.
- Experiment: on eBay, randomly vary good prices and shipping costs of Xbox games, keeping the total cost fixed
- Result: using a lower price leads to more bidders and higher revenue
- Interpretation: shoppers forget to think about shipping costs when bidding
- **EE Implication:** Energy costs are less salient than up front costs, so people might underweight them

Which choice leads to greater fuel savings?

(A) a 15 mpg Cadillac Escalade instead of a 12 mpg Chevrolet Suburban

(B) a 50 mpg Toyota Prius instead of a 29 mpg Toyota Corolla?

Compare Side-by-Side

Fuel Economy		Energy and Environment	Safety	Specs
Personalize	2013 Toyota Prius X		2013 Toyota Corolla X	
	Hybrid Vehicle			
				
	1.8 L, 4 cyl, Automatic (variable gear ratios)		1.8 L, 4 cyl, Automatic 4-spd	
	MSRP: \$24,200 - \$30,005		MSRP: \$16,230 - \$20,550	
EPA Fuel Economy				
Miles per Gallon	REGULAR GASOLINE		REGULAR GASOLINE	
	50		29	
	Combined		Combined	
	51	48	26	34
	City	Highway	City	Highway

Source: Wolfram blog post (2013)

Assume you would drive the same distance and speed in each car.

The MPG Illusion

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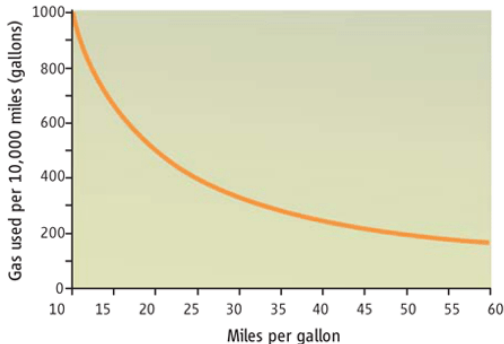
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Assume you're going to drive 100 miles,

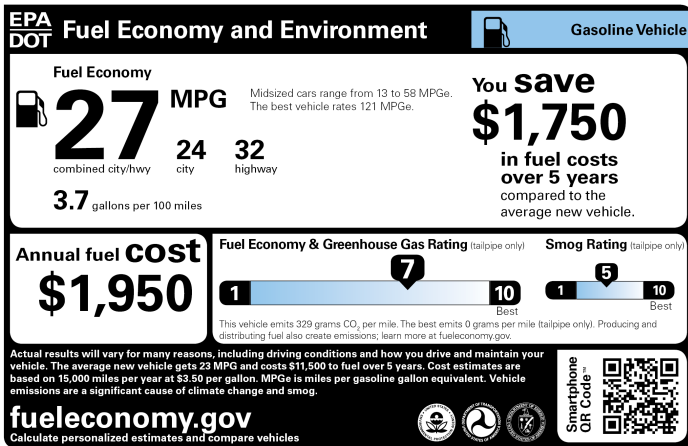
- (A) 8.3 gal in the Suburban vs 6.7 gal in the Escalade → save 1.6
- (B) 2 gal in the Prius vs 3.4 in the → save 1.4
- So the correct answer is A. Why?



Source: Larrick and Soll (2008)

Gas demand = miles driven * (gas/mile)

What we care about is GPM, not MPG!



Consumers can still choose gas guzzlers if they want, but now they have better information to make their decision.

A model of consumer irrationality

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Summary

- In a standard econ model, a demand curve traces out consumers' **true marginal willingness to pay for a good**.
 - Consumers know how much their **private** (personal) surplus would increase by purchasing the good.
 - They rationally purchase if $MB > P$.

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Summary

- In a standard econ model, a demand curve traces out consumers' **true marginal willingness to pay for a good**.
 - Consumers know how much their **private** (personal) surplus would increase by purchasing the good.
 - They rationally purchase if $MB > P$.
- If consumers are not perfectly rational, they may purchase (not purchase) a good even when their true marginal surplus is lower (higher) than the price.
- To model this, we will introduce a new demand curve which reflects consumers' **perceived** marginal willingness to pay.
 - I'll call this their **Decision Marginal Benefits** (ie the MB they have in their heads when they decide to buy or not)
- **Important:** Regardless of what consumers thought when they purchased a good, **their actual realized utility is determined by their true MB**.
 - To get surplus, we integrate under rational MB, not decision MB.

Updating the EE Gap model to account for behavioral biases

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Summary

- Let γ represent the rate at which consumers value future energy savings. ($\gamma = 1$ is “rational”)
- The EE Gap hypothesis is that consumers **undervalue** (discounted) future energy savings. ($\gamma < 1$)
- Their decision rule for adoption becomes:

$$\text{Adopt if: } c_E - c_I < \gamma \frac{(e_I - e_E)p}{(1+r)} * m$$

- This determines the quantity of E .

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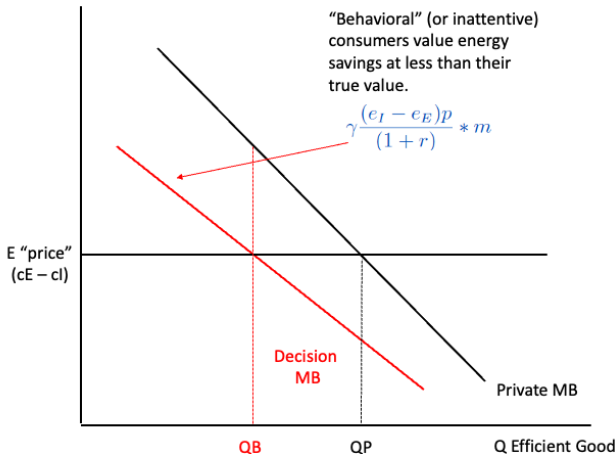
$$\text{Adopt if: } c_E - c_I < \gamma \frac{(e_I - e_E)p}{(1 + r)} * m$$

- This determines the quantity of E .
- But ultimate energy expenses are what they are. (ie $\gamma = 1$)
 - Regardless of what you thought when you bought an Escalade, it really does only get 15 miles per gallon.

Updating the model to account for consumers undervaluing energy savings

Consumers value a future (discounted) dollar saved at $\gamma < 1$

$$\text{Adopt if: } c_E - c_I < \gamma \frac{(e_I - e_E)p}{(1+r)} * m$$



Now increasing energy efficiency can actually increase private benefits

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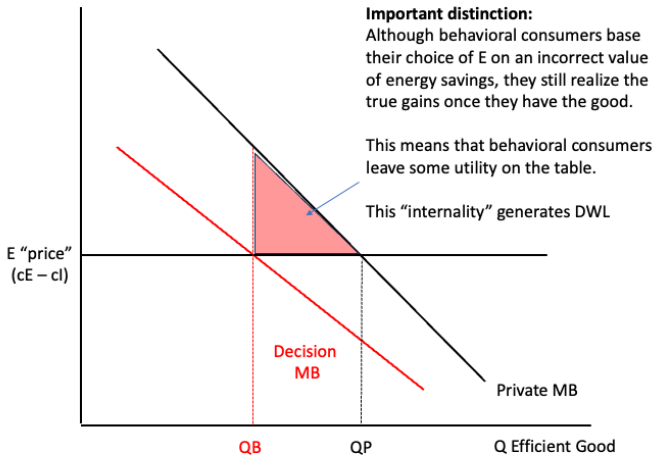
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Now increasing energy efficiency can actually reduce both externalities and internalities

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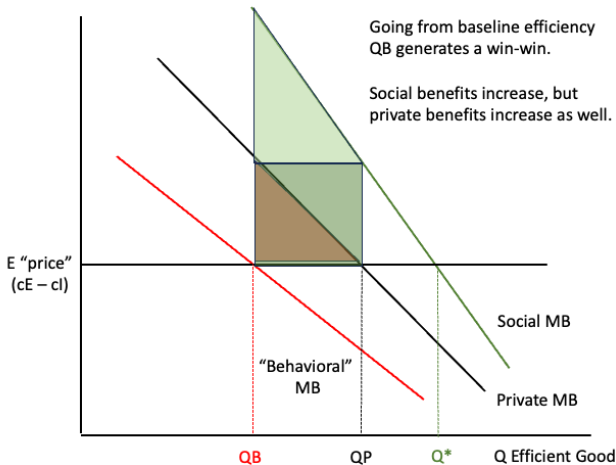
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McKinsey famously asserted EE is a free lunch

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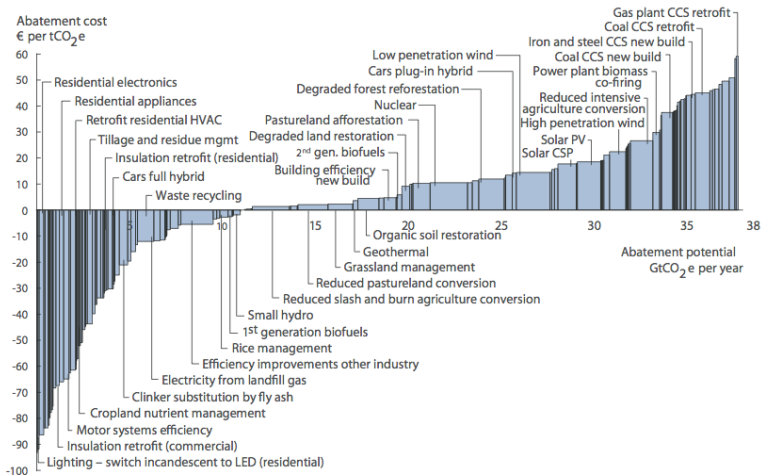
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Global GHG abatement cost curve beyond business-as-usual - 2030



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO₂ emissions of each never was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

Source: McKinsey & Company (2009)

Energy Efficiency: Is there a free lunch?



Electric Cars Are Better for the Planet – and Often Your Budget, Too

By [Veronica Penney](#) Jan. 15, 2021

Electric vehicles are better for the climate than gas-powered cars, but many Americans are still reluctant to buy them. One reason: The larger upfront cost.

New data published Thursday shows that despite the higher sticker price, electric cars may actually save drivers money in the long-run.

What would you need to know to make this assertion?

How do we really know people are making mistakes?

$$c_E - c_I < \frac{(e_I - e_E)p}{(1 + r)} * m$$

- Need to know:
 - True energy savings ($E_I - E_E$)
 - True usage m and energy prices p (for everyone)
 - Real discount rate r (person-specific)
- If we mis-measure any of these, we might incorrectly conclude that people are making mistakes
- What are some other “rational” explanations for low takeup?

Some “rational” explanations for low takeup

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Information Problems

- Principal-agent issues (e.g., renters/landlords – Davis 2011)
- Asymmetric information (research on residential construction, Jaffe & Stavins 1995)

Capital Market Failures

- Liquidity constraints / lack of access to credit

Measurement error

- Uncertainty over benefits, energy prices

Imperfect substitutes

- Sometimes *E* and *I* aren't perfect substitutes. For example, EVs. Why?

Information Problems

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Imperfect substitutes

- Sometimes *E* and *I* aren't perfect substitutes. For example, EVs. Why?

Important: If we assume the people are making mistakes, but in reality one of these rational explanations is true, we might incorrectly conclude that there is an energy efficiency gap. Policy forcing people to adopt energy efficient technologies in this case could be inefficient or even harmful.

Nudges and Libertarian Paternalism

- Governments frequently intervene to protect us from:
 - Imperfect information
 - Failure to maximize long-run welfare
- Many times the “solution” is to outright **ban** the activity in question. Examples:
 - Drug, alcohol, and cigarette taxes and bans
 - Food and consumer product safety standards
 - Helmet and seat belt laws
 - Usury laws and other financial services regulation

Biden administration puts the final nail in the coffin for incandescent light bulbs

PUBLISHED WED, AUG 2 2023-1:46 PM EDT



Catherine Clifford
[@IN/CATCLIFFORD/](#)
[@CATCLIFFORD](#)

WATCH LIVE

KEY POINTS

- On Tuesday, the Biden administration put the final nail in the coffin for incandescent light bulbs, the result of a decade-plus-long legislative path. The first step in the journey began in 2007 when the Energy Independence and Security Act passed.
- The phase-out of light bulbs that have energy efficiency standards of more than 45 lumens per watt has been gradual. On Tuesday, the last stage of that gradual roll-out ended.

Motivation: The Lightbulb Paradox

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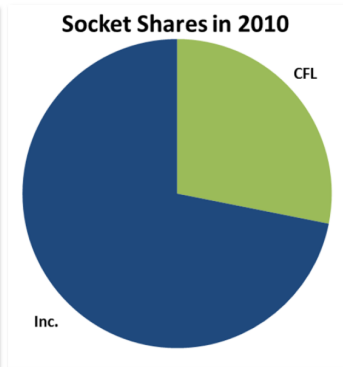
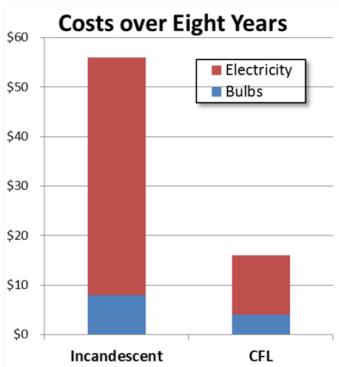
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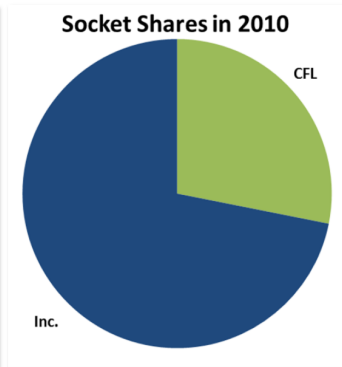
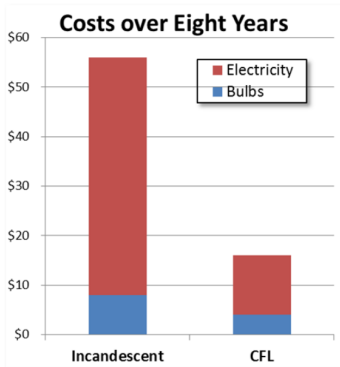
Summary



Source: Allcott & Taubinsky (2015)

- Incandescents cost less (\$1 vs \$4), but don't last as long
- Dominant narrative about low takeup: People acting **irrationally** (lack of information, energy costs not salient, etc)

Motivation: The Lightbulb Paradox



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- Incandescents cost less (\$1 vs \$4), but don't last as long
- Dominant narrative about low takeup: People acting **irrationally** (lack of information, energy costs not salient, etc)

Are we sure *everyone* is making a mistake? What are some **Rational** explanations?

Appealing alternative: policy “nudges”

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Summary

- Insights from behavioral economics has lead to interest in a softer form of paternalism, known as “Libertarian Paternalism”
 - *Nudge*, by Sunstein and Thaler (highly recommended summer reading)
- Not an oxymoron
 - Idea is to design policy in that can correct behavioral failures, but still allows people to make whatever choice they want

Lightbulb experiment

Evaluating Behaviorally Motivated Policy: Experimental Evidence from the Lightbulb Market[†]

By HUNT ALLCOTT AND DMITRY TAUBINSKY*

Imperfect information and inattention to energy costs are important potential motivations for energy efficiency standards and subsidies. We evaluate these motivations in the lightbulb market using a theoretical model and two randomized experiments. We derive welfare effects as functions of reduced-form sufficient statistics capturing economic and psychological parameters, which we estimate using a novel within-subject information disclosure experiment. The main results suggest that moderate subsidies for energy-efficient lightbulbs may increase welfare, but informational and attentional biases alone do not justify a ban on incandescent lightbulbs. Our results and techniques generate broader methodological insights into welfare analysis with misoptimizing consumers. (JEL D12, D83, H21, H31, L67, Q41, Q48)

“The Lightbulb Paradox”

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We have given you a \$10 shopping budget to purchase a package of light bulbs. Your first 15 purchase decisions will concern the two packages of light bulbs shown below.

Choice A
Philips 60-Watt-Equivalent
Compact Fluorescent Light Bulb, 1-Pack



Choice B
Philips 60-Watt Incandescent
Light Bulbs, 4-Pack



[Click for detailed product information](#)

Between the 15 decisions, the only thing that varies is the price. Each of these decisions has a chance of being the one choice (out of 30) that will become your official purchase, so you should think about each purchase carefully. Whatever money you do not spend on the light bulbs, you get to keep: any remaining money will be provided to you as cash-equivalent bonus points. Please think about each decision carefully.

Here is an example of how this might work. After you make all your decisions, suppose that Decision Number 6 from the set below were selected as your official purchase.

CFLs last longer than incandescents. At average usage:

- Incandescents burn out and have to be replaced every year.
- CFLs burn out and have to be replaced every eight years.

If one incandescent bulb costs \$1 and one CFL costs \$4, this means that the total purchase prices for eight years of light are:

- \$8 for incandescents
- \$4 for CFLs

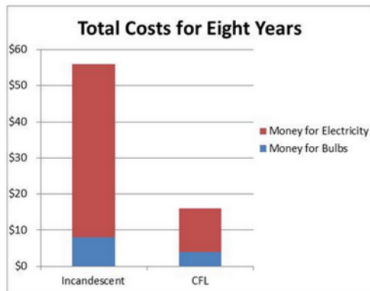
Also, CFLs use less electricity than incandescents. At national average usage and electricity prices:

- A standard (60-Watt) incandescent uses \$6 in electricity each year.
- An equivalent CFL uses \$1.50 in electricity each year.

Thus, for eight years of light, the total costs to purchase bulbs and electricity would be:

- \$56 for incandescents: \$8 for the bulbs plus \$48 for electricity
- \$16 for a CFL: \$4 for the bulbs plus \$12 for electricity

The graph below illustrates this:



AT ask people to make 15 choices with different relative prices. Why?

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EE gap

Behavioral
ExplanationsRational
Explanations

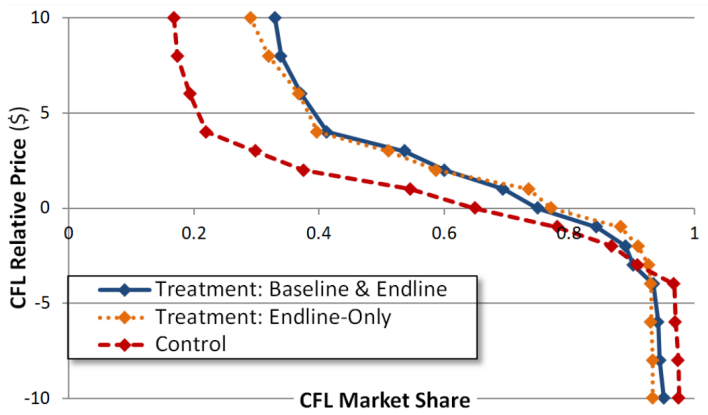
Nudges

Lightbulb
experiment

Summary

Now please make your decisions for each of the 15 choices below.

Decision Number	Choice A 60-Watt-Equivalent Compact Fluorescent Light Bulb, 1-Pack	Choice B 60-Watt Incandescent Light Bulbs, 4-Pack
	Purchase Choice A for free	Purchase Choice B for \$10
1)	☐	☐
	Purchase Choice A for free	Purchase Choice B for \$8
2)	☐	☐
	Purchase Choice A for free	Purchase Choice B for \$6
3)	☐	☐
	Purchase Choice A for free	Purchase Choice B for \$4
4)	☐	☐
	Purchase Choice A for \$1	Purchase Choice B for \$4
5)	☐	☐
	Purchase Choice A for \$2	Purchase Choice B for \$4



Source: Allcott & Taubinsky (2015)

- For many consumers, $\gamma < 1$
- But some consumers *really* do not like CFLs

Maybe banning incandescents isn't a good idea?

Welfare Analysis Under Alternative Assumptions

Scenario	Optimal	Ban Welfare	Ban Welfare
	Subsidy	Effect	Effect
	(\$/pack)	(\$/package)	(% of surplus)
1 Base	3	-0.44	-41

- A subsidy of \$3 would maximize (private) welfare
- But a ban would not increase welfare (based on internalities alone)

- I and E may differ on non-energy dimensions (ie light quality)
 - if goods aren't perfect substitutes, and people value them based on non-energy dimensions, we need to account for this.
- let ξ represent the incremental utility “cost” of I .
- now the decision rule is adopt E if:

$$\gamma pm(e_I - e_E)/(1 + r) > (c_E - c_I) + \xi$$

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- An energy efficiency “gap” will exist whenever $\gamma < 1$
 - ie consumers are inattentive to or uninformed about energy costs
- but simply observing that people are not buying the efficient good based solely on energy and up front costs is not enough to conclude this.

Summary

- Long-standing interest in energy efficiency due to externalities.
- More popular than Pigouvian taxes because it seems like a “win-win”
- We describe this claim in a simple economic model that simply says that the net gains to consumers are the energy savings less the up-front cost difference.

$$\text{Net Savings} = pm(e_I - e_E)/(1 + r) - \xi - (c_E - c_I)$$

- failure to adopt when net gains are positive is a mistake (and correcting that mistake makes people better off)
- model clarifies what we need to know to conclude people are making mistakes

Measuring exactly how large the EE gap is is challenging

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- people are heterogeneous
 - particularly wrt to usage m
 - what is the right r ? credit card rate?
 - even if you know those values on average, you would get it wrong for half the population
- goods involve many attributes, not just energy:
 - ξ probably not zero (as in light bulbs)
- **Next week:** we actually don't know $(e_I - e_E)$ with certainty
 - engineering estimates can differ in the real world for lots of reasons

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For all these reasons, many simple calculations of the energy efficiency gap (ie McKinsey) are probably misleading.