Deconstructing the Energy-Efficiency Gap: Conceptual Frameworks and Evidence

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Energy-efficient (EE) technologies offer considerable promise for reducing the financial costs and environmental damages associated with energy use, but these technologies appear not to be adopted to the degree that appears justified, even on a purely private basis.

We present two complementary frameworks for understanding the EE gap. First, we build upon previous literature (Jaffe and Stavins 1994; Gillingham, Newell, and Palmer 2009) by dividing potential explanations for the gap into three categories: market failures, behavioral explanations, and model and measurement errors. Second, we examine the elements of cost-minimizing EE decisions, the typical benchmark used in assessing the gap's magnitude.

I. Potential Explanations

First, potential market-failure explanations for the EE gap include information asymmetries and imperfections in markets for energy, capital, and innovation.

Second, potential behavioral explanations include myopia, cognitive limitations, inattentiveness, loss aversion and reference dependence, and systematically biased beliefs.

Third, there are potential model and measurement explanations. These feature reasons why the adoption rate of EE technology may not be as paradoxical as it first appears. Potential sources of model and measurement error include unobserved costs or overstated energy savings from adoption, ignored product attributes, heterogeneity across potential adopters, use of inappropriate discount rates, and uncertainty.

Determining the validity of candidate explanations—and the degree to which each contributes to the EE gap—are crucial for crafting sensible public policy responses.

II. Elements of Cost-Minimizing Decisions

To provide structure to the diverse set of economic elements that enter into adoption decisions related to energy efficiency, it is useful to examine the elements of cost-minimizing technology adoption decisions:

$$(1)\ \min K(E) + \underbrace{O(E, P_E) \times D(r, T)}_{\text{discounted operating costs}} + C,$$

where equipment purchase cost $K(E)$ is a function of annual energy use E; discounted operating costs are equal to annual operating cost $O(E, P_E)$ multiplied by a discount factor $D(r, T)$; O is a function of energy use E and the price of energy P_E; D is a function of the discount rate r and the relevant time horizon T; and C is other costs. This formula is deliberately simple, and does not explicitly account for all relevant factors, such as uncertainty. Nonetheless, the decomposition suggests four questions around which to organize assessment of the EE gap.

Are product offerings and pricing efficient?—Firms may under-invest in R&D due to spillovers, distorting EE product offerings. Or some products may be sold at "high" prices relative to the static social optimum if firms charge above marginal cost to recoup fixed costs of investment. Also, exercise of market power could distort prices relative to a competitive benchmark. Finally, consumers may not demand EE products simply because they lack information.

These theoretical points are clear, but empirical evidence specific to EE is limited. The exception is research on whether consumers (Palmer et al. 2013) and firms (Anderson and Newell 2004) lack adequate EE information.

In theory and in practice, an informed third party can fill this information gap. The welfare effects of such information provision depend on the resource cost of information provision and also on its form. For example, government labels influence consumer decisions (Newell and Siikamäki 2014), but coarse information provision can distort product offerings. Few studies credibly distinguish the effects of information provision from competing explanations.

Research could be usefully directed toward evaluating and improving the effectiveness and efficiency of current information policies.

Are energy costs mispriced or misunderstood?—Of course, even if consumers make privately optimal decisions, adoption of EE technology may be slower than is socially optimal due to unpriced externalities of energy consumption.

The theoretical arguments are robust, and empirical evidence for the inefficient pricing of energy is considerable. For example, the environmental, congestion, and accident externalities of gasoline consumption are on the order of $2-3 per gallon (Parry, Walls, and Harrington 2007), and estimates of the social costs of non-climate damages from coal-powered electricity are 3–4 cents per kilowatt-hour (National Research Council 2010). However, many of these externalities are regulated, and thereby indirectly or directly priced.

Other market distortions, such as electricity price regulation, make it difficult to judge whether electricity prices are too low overall. Electricity and natural gas prices may be inefficiently high due to pricing that recoups fixed costs through marginal fees (Davis and Muehlegger 2010).

Another potential explanation for the EE gap is that consumers' expectations about future energy prices or use are systematically biased downward. There is only mixed evidence, and a fundamental challenge is to identify separately beliefs and preferences. Further research would be useful to isolate the effect of information policies on beliefs.

Analytical assumptions can contribute to the EE gap, by overestimating projected energy savings or failing to account for consumer heterogeneity. Engineering-economic analyses typically estimate energy savings that exceed savings observed in *ex post* energy consumption data (Davis, Fuchs, and Gertler 2014). Ignoring heterogeneity can bias energy savings estimates upward: systematic differences between past and future adopters can drive a wedge between observed and potential returns for a given investment. There are opportunities for more research in this area, particularly in the transportation, commercial, and industrial sectors.

Are product choices cost-minimizing?— Product choices may not minimize present value costs. Principal-agent conflicts—"split incentives"—are among the most widely cited market failure explanations for the EE gap. Examples include landlord-tenant and builder-buyer conflicts, in which agents make sub-optimal capital investment choices from the perspective of the principals. Similar agency conflicts are possible within firms. Empirical studies have compared owner-occupied and rental properties and found compelling evidence consistent with principal-agent conflicts (Gillingham, Harding, and Rapson 2012), but the economic magnitude of EE differences due to these principal-agent conflicts may be small.

Behavioral phenomena could also explain choices that are not cost-minimizing. Consumers may be inattentive to energy costs when purchasing energy-using products, but such lack of attention is not necessarily irrational. Costly information acquisition can justify decisions that appear privately sub-optimal (Sallee 2013), and therefore policies that reduce inattention may be warranted, such as information provision, which raises the salience of EE, or taxes on energy, which raise the cost of inattention (Allcott, Mullainathan, and Taubinsky 2014). But to guide policy, further research is needed to isolate inattention from imperfect information.

Three other phenomena at the intersection of psychology and economics may help explain the energy-efficiency gap. First, prospect theory, which demonstrates how reference points and loss aversion can affect economic decisions, is consistent with consumer demand for vehicle fuel economy (Greene, Evans, and Hiestand 2013) and energy use (Goldstein, Cialdini, and Griskevicius 2008). Second, cognitive limitations (or "bounded rationality") could inhibit consumers from properly balancing benefits and costs when comparing energy-consuming products (Allcott 2013). Finally, consumer myopia or shortsightedness could lead to suboptimal adoption of EE technology. Here, very few studies credibly isolate myopia from other explanations and the evidence is mixed (Allcott and Wozny 2013; Busse, Knittel, and Zettelmeyer 2013).

The empirical evidence on whether energy-consuming product choices are cost-minimizing ranges from strong to weak across these candidate explanations, leaving room for new research in this realm, particularly experiments to isolate and evaluate competing explanations.

Do other costs inhibit EE?—If products of varying efficiencies differ from each other in ways that are omitted by engineering and econometric analysis but that are important to consumers, this could contribute to the misidentification of an energy-efficiency gap. In principle, econometric methods can address these issues by including data on product attributes or subsuming unobserved attributes into a product-specific error term. In practice, this has been limited by data and computational constraints. One solution may be to use panel data to eliminate time-invariant unobserved product attributes. Another promising approach is the use of geographic variation and an assumption on spatial invariance of consumer preferences to eliminate product attributes that do not vary across markets (Houde 2014).

A second possibility is that analysts fail to take sufficient account of the costs of EE investments. Examples include time spent researching product alternatives, unobserved implementation costs, and costs of reallocating resources within a firm. These costs are not easily quantified, but they can be real barriers to investment.

These cost issues merit some priority for research, including understanding consumer demand for relevant product attributes.

III. Conclusions

Debate over the EE gap is not new, but there has been a striking increase in policy interest and investment in EE over the past decade, plus a coincident resurgence of academic research. Recent methodological advances provide the opportunity for applied researchers to evaluate existing and proposed policies. Our reframing of key questions and our review of recent literature can aid scholars in doing this.

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