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Bridging the Energy Efficiency Gap

Policy Insights from Economic Theory and Empirical Evidence

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Abstract

Despite several decades of government policies to promote energy efficiency, estimates of the costs and benefits of such policies remain controversial. At the heart of the controversy is whether there is an "energy efficiency gap," whereby consumers and firms fail to make seemingly positive net present value energy saving investments. High implicit discount rates, undervaluation of future fuel savings, and negative cost energy efficiency measures have all been discussed as evidence of the existence of a gap. We review explanations for an energy efficiency gap, including reasons why the size of the gap may be overstated, neoclassical explanations for a gap, and recent evidence from behavioral economics that has potential to help us understand why a gap could exist. Our review raises fundamental questions about traditional welfare analysis, yet we find the alternatives offered in the literature to be far from ready for use in policy analysis. Nevertheless, we offer several suggestions for policymakers and for future economic research.

Key Words: energy efficiency, market failures, behavioral failures, behavioral economics

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Introduction

In recent years, energy policy discussions have focused increasingly on enhancing the efficiency with which the economy uses energy to deliver services such as transport, refrigeration, cooking, and space heating and cooling. This focus on energy efficiency is motivated by a desire to reduce emissions of CO_2 and other pollutants, increase the security of energy supply, and reduce the need for new energy supply infrastructure, such as difficult-to-site power plants and transmission lines. In the absence of a national policy to cap or tax CO_2 emissions in most countries, the promotion of low or zero emitting energy technologies through a mixture of standards and incentives has become the main policy mechanism for addressing concerns about global warming. More efficient end-use technologies are often an important component of a clean energy technology portfolio.

Several studies by McKinsey and Company (Creyts et al. 2007; Granade et al. 2009; McKinsey & Company 2009) have highlighted the potential to reduce energy consumption and CO_2 emissions through investments in energy efficient equipment and appliances, with the most recent suggesting that 835 megatons of carbon dioxide equivalent could be reduced in 2030 at a net savings of over $45 billion (in 2005 dollars). These and other studies (Chandler and Brown 2009; EPRI 2009; Meier, Wright, and Rosenfeld 1983; National Academy of Sciences 2009; Stoft 1995) suggest that the present discounted value of these future energy savings greatly exceeds the upfront cost of energy efficient products. The ideas underlying these studies have played a critical role in policy. For example, the Draft Regulatory Impact Analysis of the recently tightened U.S. light duty vehicle greenhouse gas/fuel economy standards finds that the present discounted value of fuel savings from the policy exceeds its initial costs—implying reductions in CO_2 emissions at no cost (NHTSA 2011).

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The failure of consumers to make energy saving investments that have positive net present value has been the subject of an economics literature dating back to Hausman (1979) and suggests that when selecting the energy efficiency of a purchased durable good, individuals behave as if they heavily discount future energy savings (Train 1985). More recently, studies of vehicle purchasing behavior find that individuals behave as if they "undervalue" future fuel savings (Allcott and Wozny 2012) or the product attribute of energy efficiency (Helfand and Wolverton 2011). All of these studies suggest that the way individuals make decisions about energy efficiency leads to a slower diffusion of energy efficient products than would be expected if consumers made all positive net present value investments. This phenomenon has come to be known as the *energy efficiency gap* or the *energy efficiency paradox*. In some cases, the energy efficiency gap is defined even more broadly to describe the slower than socially optimal rate of diffusion of energy efficient products (Jaffe and Stavins 1994).Yet, the very existence of the energy efficiency gap has been met with skepticism by many economists, and the use of analyses showing positive net present value energy efficiency investments for policy support has caused even more skepticism. The underlying issue for determining the existence of an energy efficiency gap is whether individual decision-making is modeled correctly and whether all relevant costs are accounted for.

Economists have long recognized that market failures, including environmental externalities, inefficient pricing of energy, lack of information, and principal-agent issues, can lead to inefficiently low levels of investment in energy efficiency (Gillingham, Newell, and Palmer 2009). Recently, some economists have proposed that systematic behavioral biases in consumer decision-making may explain the apparent energy efficiency gap (Allcott, Mullainathan, and Taubinsky 2012; Tietenberg 2009). Proponents of this view argue that there may be a role for policies that promote energy efficiency and improve economic efficiency but that are not motivated by traditional market failures.

This article reviews the current state of the literature on the energy efficiency gap. We discuss explanations for the gap, based on both neoclassical economic theory and the latest advances in behavioral economics, examine the policy implications of market and behavioral failures, and review the empirical evidence concerning policy instruments that have been used to promote energy efficiency. Our review is guided by the existing literature, which focuses on consumers, but we include evidence on firms when it is available and relevant.[1]

The remainder of the article is organized as follows. In the next section, we provide reasons why the energy efficiency gap may be over-estimated. This is followed by a discussion of the explanations for the gap, including market failures and behavioral anomalies. We then explore some of the deeper questions about welfare analysis of policy that are raised by behavioral anomalies. Next we discuss the policy implications of market and behavioral failures and review empirical evidence about the cost and effectiveness of energy efficiency policies, with a focus on policies in the United States. The final section summarizes our findings and discusses priorities for future research.

Why the Energy Efficiency Gap May be Small

Despite more than 30 years of research on the energy efficiency gap, the issue of its *size* remains unresolved. Many economists believe that consumer choices reveal more about the economics of energy efficiency improvements than do engineering calculations. If engineering estimates of the energy savings potential from seemingly cost-effective investments fail to include some costs or model the consumer's decision inappropriately, then the assessment of what is optimal from the consumer's perspective will be incorrect. Thus, the engineering approach will result in the net benefits from energy efficiency investments being overstated, which means the gap may be much smaller than estimated or there may be no gap at all (Metcalf and Hassett 1999; Smith and Moore 2010). More broadly, the gap may be over-estimated because of hidden costs, consumer heterogeneity, uncertainty, over-estimated savings, and the rebound effect.

Hidden Costs

Hidden costs may be as simple as the administrative costs of an energy efficiency program or the time costs of finding or installing a more energy efficient product that is as reliable as the more familiar alternative product. Hidden costs also include the opportunity cost of the services or alternative investments that consumers forgo in order to invest in energy

[1] Firms may differ from consumers to the extent that they employ professional energy managers. However, such a focus on energy management is not universal among businesses. Thus, firms may face many of the same issues in their efficiency investment practices as consumers.

efficiency. One potentially important opportunity cost is a decrease in the quality of the energy service provided. For example, more energy efficient lighting may come at the cost of less pleasing or lower quality light. Higher vehicle fuel economy may be bundled with less desirable attributes such as small size or less acceleration. The evaluation of energy efficiency investments may also cause firms to divert scarce managerial attention from projects that may be more important to the firm.

Anderson and Newell (2004) examine free energy audits for manufacturing plants and find that roughly half of the projects recommended by auditors were not adopted despite extremely short payback periods. The plant managers indicated that as much as 93 percent of the projects were rejected for economic reasons, which were often related to high opportunity costs. Unfortunately, differences in quality and other opportunity costs are difficult to measure and must be evaluated on a case-by-case basis.

Consumer Heterogeneity

Consumer heterogeneity may also help to explain why some estimates suggest a gap exists. Products that appear financially attractive for the average consumer may not be attractive for some consumers because of differences in preferences, expected use of the product, and the cost of borrowing (Allcott and Greenstone 2012; Golove and Eto 1996). For example, a consumer purchasing an air conditioner for a summer home that is used for only a few weeks each year may be better off purchasing a less expensive, less energy efficient air conditioner than the average person would purchase. Bento, Li, and Roth (2012) use a Monte Carlo experiment to show that heterogeneity in preferences may bias empirical studies toward finding that consumers undervalue savings, since consumers with higher preferences for future fuel savings choose more fuel-efficient products, leading to a selection bias.

Uncertainty

Investing in energy efficiency may be risky due to the irreversibility of the investment and fluctuating energy prices. If energy prices fall, then the return on the investment declines. Using a model of consumer decision-making under uncertainty, Hassett and Metcalf (1993) and Metcalf (1994) show that including uncertainty increases by four or five times the rate of return needed to make a yes/no energy efficiency investment attractive. However, Sanstad, Blumstein, and Stoft (1995) point out that this option value may not be sufficient to explain high observed implicit discount rates in many settings. Moreover, Baker (2012) shows that the Hassett and Metcalf (1993) result does not apply when there are multiple choices with different efficiencies.

Nevertheless, Anderson and Newell (2004) find that risk is a common explanation for firms rejecting energy audit recommendations.[2] Uncertainty about product performance may have a similar effect. In the presence of such uncertainties, consumers and firms may be better off delaying the investment until the uncertainties are resolved (Dixit and Pindyck 1994).

Overestimating Energy Savings

Engineering calculations may be prone to overstating the energy savings from particular investments. In some cases, this can arise from failure to account for interactions between different investments such as efficient lighting and heating. Engineering simulations may also tend to assume perfect installation and maintenance of the energy efficiency investments, thereby overstating the projected energy savings. For example, in a randomized controlled experiment in Florida, Dubin, Meidema, and Chandran (1986) find that engineering simulations of the energy savings from residential energy efficiency improvements overstated the returns by eight to 13 percent.

Rebound Effect

Engineering approaches also often underestimate the size of the gap by assuming that energy service demand is constant before and after the efficiency investment. However, to the extent that consumers use more energy services because usage costs are lower, a response known as the *rebound effect*, consumer choice theory suggests that welfare increases. Thus, the engineering estimates would understate the rate of economically efficient technology diffusion.[3] Conversely, if the rebound effect is not accounted for, then estimates of cost-effective energy savings are likely to be biased upwards.

[2] However, it may difficult to distinguish between risk aversion and inertia (Stern and Aronson 1984).

[3] We thank Tim Brennan for pointing this out.

Explaining the Gap: Market Failures

Despite the many reasons why the size of the energy efficiency gap maybe overestimated, there are also several market failures that suggest the gap is real: imperfect information, principal-agent issues, credit constraints, learning-by-using, and regulatory failures.[4]

Imperfect Information for Consumers.

If consumers have imperfect information about the energy savings from investing in more energy efficient products, then they may be disinclined to invest in them. In some cases, sellers may have better information than buyers but are unable to credibly convey that information to the market, which leads to a market failure from asymmetric information. Imperfect or asymmetric information may exacerbate the apparent risk of energy efficiency investments and may help explain why Anderson and Newell (2004) find that project risk is an important reason that firms decide not to adopt energy efficiency measures recommended in energy audits.

Principal-Agent Issues

A principal-agent problem arises when one party makes a decision relating to energy use, but another party pays or benefits from that decision. For example, the landlord may pay for heating, while the tenant chooses how much energy to use. Alternatively, the landlord may choose the energy efficiency of the dwelling, while the tenant pays for energy use but imperfectly observes the efficiency when the rental contract is executed. There is empirical evidence suggesting that such situations may lead to increased energy use or reduced energy efficiency in the residential setting (Davis 2012; Gillingham, Harding, and Rapson 2012), although the estimated magnitude of the energy losses from such split incentives was relatively small. Principal-agent problems may also apply to organizations, such as when different individuals are responsible for energy bills and capital accounts. Principal-agent issues in organizations have been widely discussed (Tietenberg 2009), their effects have not been quantified.

[4] Economists have long noted that, to the extent that environmental and national security externalities have not been addressed by policy, there will be a divergence between the market rate of adoption of energy efficient products and the socially efficient rate of adoption (Convery 2011; Jaffe and Stavins 1994; Levine et al. 1995). However, the benefits from reducing externalities are often treated separately in energy efficiency analyses and thus are generally not considered to be part of the energy efficiency gap.

Credit Constraints

Credit (or liquidity) constraints may also help explain the energy efficiency gap (Golove and Eto 1996). If there is a high upfront cost, then limited access to credit may prevent some consumers from purchasing a more energy efficient product or from making efficiency enhancing improvements to their homes. Limited access to credit may result from credit rationing, which can occur when asymmetric information on credit risk prevents lenders from distinguishing between borrowers who are good or bad credit risks. In the energy efficiency context, lack of information on the part of the lender about the payoff from efficiency investments may contribute to credit rationing. In particular, investments with particularly high energy savings payoffs, which could reduce the risk of default, may not be made because lenders cannot distinguish them from investments with low payoffs. Credit rationing may be especially acute for borrowers considering investments with high energy savings payoffs, and a correspondingly low risk of default, but who also happen to have poor credit (Palmer, Walls, and Gerarden 2012).

Learning-by-Using

The process of using a new energy efficient technology may produce knowledge about how to best use the product, and this knowledge may spill over to others in the future. In this case, early users will have less incentive to adopt the energy efficient product than is socially optimal. Mulder, DeGroot, and Wofkes (2003) present a simulation model that represents such effects in firm decisions regarding replacement of inferior technologies, including those that are energy inefficient. However, we are not aware of any empirical evidence on learning-by-using for energy efficient technologies.

Regulatory Failures

Economic regulation of electricity markets results in prices that differ from marginal costs and this difference can distort incentives for investment in energy efficiency. If regulated prices fall below marginal cost, then regulation contributes to the efficiency gap, although the opposite can also be true. This pricing distortion has a temporal dimension because consumers generally face time-invariant electricity prices. This means consumers do not see changes in electricity costs between expensive peak periods and lower cost off-peak periods, when price tends to be above marginal cost (Brennan 2011). Since electricity prices exceed efficient levels for most of the day, more efficient pricing of electricity may actually result in lower demand for energy efficiency. This suggests that on net, regulatory failures are likely not an important explanation for the gap.

Explaining the Gap: Behavioral Anomalies and Failures

Beginning with the work of Kahneman and Tversky in the 1970s (e.g., Tversky and Kahneman (1974)), the field of psychology and economics (known as behavioral economics) has documented numerous cases of behavioral anomalies in which observed consumer behavior differs from the standard assumptions of neoclassical economics: consumers behave as if they maximize a self-interested utility function that does not change over time, are fully informed, use all of the information available, and process this information appropriately. The idea that behavioral anomalies may be contributing to the energy efficiency gap has been widely discussed recently in both the academic literature and the policy arena (Gillingham, Newell, and Palmer 2009; Helfand and Wolverton 2011; Shogren and Taylor 2008; Tietenberg 2009). If they are to help explain the gap, these deviations from the neoclassical assumptions must be *systematically* biased toward encouraging increased purchases of less energy efficient products.

Both economists and psychologists describe systematic biases in intertemporal decisions as creating a difference between *decision utility*, which is the utility consumers maximize at the time of the choice, and *experienced utility*, which is the utility consumers later experience due to the prior decision (Kahneman 1994; Kahneman, Wakker, and Sarin 1997). A burgeoning literature in neuroeconomics attempts to understand the neural pathways that control how consumers make decisions and receive experienced utility from those decisions (Camerer, Loewenstein, and Prelec 2005; Fehr and Rangel 2011).

It is important to distinguish between *behavioral anomalies*, in which consumer behavior appears to depart from the standard assumptions of economic theory, and *behavioral failures*, which are anomalies that lead to a systematic difference between decision utility and experienced utility. In the remainder of this section we examine anomalies that are relevant to energy efficiency. We divide these anomalies into three categories: nonstandard preferences, nonstandard beliefs, and nonstandard decision-making (DellaVigna 2009).[5]

[5] Behavioral anomalies can also be classified into prospect theory (a reference-dependent model of preferences over uncertain lotteries that differs from expected utility theory), heuristic decision-making (using simple rules to guide decisions), and bounded rationality (time or information limits on rational choices) (Gillingham, Newell, and Palmer 2009). Another classification is bounded rationality, bounded willpower, and bounded self-interest (Mullainathan and Thaler 2001)

Nonstandard Preferences

Preferences that violate neoclassical assumptions described above come in three forms: self-control problems, reference dependence, and social preference (DellaVigna 2009). The first two are relevant to the energy efficiency gap.

Self-Control Problems

By definition, self-control problems are a behavioral failure. Self-control problems are situations in which consumers appear to have time-inconsistent preferences. That is, consumers appear to take a long-term view of decisions about outcomes that will occur in the distant future, but as the future approaches, the discount rate used to evaluate decisions increases. These decisions may concern unfulfilled plans or commitments to make "good" investments such as exercising more, stopping smoking, eating healthier, or, as suggested by Tsvetanov and Segerson (2013), investing in more energy efficient products. These time-inconsistent preferences are often formally represented by quasi-hyperbolic or (β, δ) preferences (Laibson 1997; O'Donoghue and Rabin 1999).[6] Another formal model of self-control problems is the model of Gul and Pesendorfer (2001), an axiomatic approach that emphasizes preferences over sets of alternatives. Tsvetanov and Segerson (2013) adopt the Gul and Pesendorfer self-control framework to explain the energy efficiency gap and Tsvetanov and Segerson (2013) empirically show that household refrigerator choices appear consistent with self-control problems, thus offering a possible explanation for the gap.

Reference-Dependent Preferences

Reference-dependent preferences refer to a situation of decision-making under uncertainty where the consumer's utility from any outcome depends on the outcome's relationship to a particular reference point, rather than maximizing expected utility. For example, there is empirical evidence that in many cases consumers exhibit loss aversion (i.e., the reference point is a zero payoff), which means that the decline in utility from a relative loss is much larger than the increase in utility from an equivalent relative gain (Tversky and Kahneman 1981).[7]

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[6] Quasi-hyperbolic or (β, δ) preferences model the presented discounted utility at time t, U_t, as the following function of the per-period utility u_t: $U_t = u_t + \beta\delta u_{t+1} + \beta\delta^2 u_{t+2} + \cdots$. In this formulation, δ is the standard discount factor and $\beta \leq 1$ captures self-control problems, while $\beta = 1$ implies the standard model of discounting.

[7] Gal (2006) suggests that inertia may be an equally valid explanation for many phenomena attributable to loss aversion.

Greene, German, and Delucchi (2009) argue that loss aversion can help explain the energy efficiency gap in the context of vehicles. When deciding whether or not to purchase a more energy-efficient vehicle, consumers are likely to be uncertain about future fuel prices, the actual energy efficiency improvement, and how much the vehicle will be driven. This means that if consumers are loss averse, they will weigh the potential negative payoffs so heavily that they may not purchase the more expensive energy efficient vehicle even if it would most likely have positive net benefits. However, Greene, German, and Delucchi (2009) do not provide empirical evidence of loss aversion. Moreover, reference dependent preferences do not unambiguously lead to a difference between decision utility and experienced utility, and thus may not represent a behavioral failure.

Nonstandard Beliefs

Nonstandard beliefs are systematically incorrect beliefs about the future (DellaVigna 2009). In the context of energy efficiency, Allcott (2012) uses survey data to elicit consumer beliefs about future fuel savings from a higher fuel economy vehicle to examine whether there is a systematic bias that contributes to an undervaluation of fuel economy. Allcott finds that although consumer beliefs about future fuel savings (holding driving behavior constant) do not match the known true values, it is unclear whether their beliefs are systematically biased. Moreover, if consumers do not realize ex post that their beliefs were incorrect, then it is unclear whether holding those beliefs represents a behavioral failure.

Nonstandard Decisionmaking

Decision-making processes that do not follow from the neoclassical assumptions have received the most attention in the academic literature, with studies conducted in a variety of intertemporal decision settings. The three forms of nonstandard decision-making that are relevant to the energy efficiency gap are consumers' limited attention, the framing of choices, and the use of suboptimal decision heuristics. All three forms could indicate behavioral failures.

Limited Attention

The idea that consumers have limited attention, leading them to systematically underweight certain information, lies at the heart of many of the arguments that behavioral anomalies explain the energy efficiency gap. Simon (1955) was one of the first economists to propose a model of bounded rationality, whereby consumers simplify complex decisions by processing only a subset of the available information. Broadbent (1958) found that in laboratory experiments, individuals selectively ignore messages when they are asked to focus on another message at the same time. In the field, consumers appear to be less attentive to attributes of products or prices that are less salient or obvious. For example, Chetty, Looney, and Kroft (2009) present evidence that consumers find sales taxes taken at the register to be less salient than taxes added to the list price. Lacetera, Pope, and Sydnor (2012) provide evidence that the left-most digits in odometer readings are the most salient to consumers, leading to discontinuous drops in used vehicle sales prices at 10,000 and 1,000 mile thresholds. Hossain and Morgan (2006) provide evidence that shipping costs are less salient if they are added at the end of the transaction rather than included in the initial price. In all of these cases, there appears to be a systematic bias that leads to some information effectively being ignored.

In the context of energy efficiency, the limited attention of consumers may lead them to systematically underestimate the future fuel savings from a more energy efficient product. While we might expect consumers to put more effort into estimating future fuel savings for large purchases, such as cars, limited attention may be relevant in this context as well. Turrentine and Kurani (2007) interviewed recent car buyers and found that nearly all considered future fuel savings in a very simple way that does not reflect a calculation of the present discounted value of future fuel costs. Some economists have argued that inattention to future fuel costs when making vehicle purchases may lead to a systematic undervaluation of these costs (Allcott, Mullainathan, and Taubinsky 2012). However, this has yet to be demonstrated empirically.

Framing of Choices

The way in which choices are framed has been shown to be important in a variety of complex decision settings. Bernatzi and Thaler (2002) and Duflo et al. (2006) show that presentation format can substantially affect choices by focusing attention on different subsets of the information being presented. In the context of energy efficiency, government regulators have made an effort to carefully design the mandatory fuel economy labels in order to help prevent any possible behavioral anomalies in consumers' processing of information (EPA 2010).

Suboptimal Decision Heuristics

When consumers make decisions among many choices, they may use heuristics or so-called rules of thumb to simplify the decision making process. For example, investors tend to under-diversify by investing in companies that they recognize from their home state (Huberman 2001), and studies have shown that the first candidate listed on a ballot tends to stand out and receive a boost in votes (Ho and Imai 2008). In the context of energy efficiency, heuristics may play a major role in decision-making when there are many variants of a product to choose from, such as for vehicles. In fact, Turrentine and Kurani (2007) allude to the role of heuristics in vehicle-purchasing decisions, but we are not aware of any empirical evidence on this anomaly in the context of energy efficiency, leaving this an area for future research.

Frameworks for Incorporating Behavioral Failures in Welfare Analysis

Given the evidence suggesting that different types of behavioral failures could influence energy efficiency decisions, the standard approaches to economic welfare analysis of energy efficiency policies are called into question. Standard welfare economics assumes that consumers make choices that maximize utility given available options and constraints (e.g., budget constraints). Using data on past consumption choices, the parameters of the utility function can be identified. When utility functions are calibrated to the preferences consumers reveal through their actual choices, the resulting model allows us to calculate the welfare benefits and costs of policies (Gul and Pesendorfer 2008; Houthakker 1950; Samuelson 1938, 1948). This resulting model, formalized in the weak axiom of revealed preference and the generalized axiom of revealed preference, relies on several key assumptions.

One of the most important assumptions of standard welfare economics is that consumer preferences are stable over time and thus decision utility is the same as experienced utility. Another assumption is that consumers have full information about all consumption opportunities and that preferences depend only on the attributes of the items in the choice set, and thus are unaffected by the framing of the choice set. If behavioral failures lead to biased consumer choices, then it is not clear that observed choices should be used to infer preferences. In such situations, an alternative approach that reveals preferences based on experienced utility is called for. If economists change the way welfare analysis is conducted, what do behavioral failures mean for energy efficiency policy? The remainder of this section delves into these questions by introducing libertarian paternalism and three different approaches to modifying welfare analysis to incorporate behavioral failures, and then discusses reasons why some economists are skeptical of these approaches.

Libertarian Paternalism

Several economists have suggested that policy makers adopt an approach that has come to be known as *libertarian paternalism* (Bernheim and Rangel 2004, 2007; Kling, Congdon, and Mullainathan 2011; Thaler and Sunstein 2003, 2008). They argue that given the impact of the framing of choices for consumer behavior, individuals should be allowed as much freedom as possible in their individual decision-making, but the government should establish conditions that lead to ex-post “good decisions.” A key feature of this approach to policy is that it changes the choice *setting*, but still allows all of the options in the original setting to be available to the consumer. Policies that change the choice setting have been called *nudges* (Thaler and Sunstein 2008). One example of a nudge is to make an energy efficient investment the default option. The challenge for this approach is determining what constitutes an ex-post good decision. That is, how does the policymaker know which decision is best? To date, there are three approaches that attempt to answer this question and develop a workable *behavioral welfare economics*: ancillary conditions, simulating perfectly competitive markets, and simultaneously-held preferences.

Ancillary Conditions

Bernheim and Rangel (2007, 2009) argue for combining information on observed choices with information about particular attributes of the choices, known as ancillary conditions. These ancillary conditions are any factors that affect the individual's choices but are not relevant to what the social planner would choose. These include contextual factors such as when decisions are made, how certain options are labeled, and what option is the default option. Information about ancillary conditions can then be used to extract consistent preferences from observed behavior and to measure unambiguous changes in welfare.

Unfortunately, this framework is difficult to operationalize. One must observe choices made under several different sets of ancillary conditions in order to distinguish the effects of those conditions on consumer choices from the effects of underlying preferences. However, in practice, we typically observe a choice only once. Thus, it is unlikely that we will have sufficient information to isolate the effects of ancillary conditions (Smith and Moore 2010). Choices concerning energy efficiency investments are no exception.

Simulating Perfectly Competitive Markets

Sugden (2005, 2009) proposes a different approach that simulates perfectly competitive markets and bases welfare calculations for policies on the outcomes in those simulated markets. Sugden contends that this approach is particularly useful in the presence of behavioral failures because the surplus maximizing properties of competitive markets do not depend on the rationality of individual preferences, requiring only that consumers be sensitive to prices. He further proposes implementing this framework by combining estimates of the price response for goods traded in the market with estimates from hedonic analyses of the sensitivity of market prices to non-market conditions. However, Smith and Moore (2010) point out that simulating markets is impractical in many situations, with energy efficiency likely to be among them.

Simultaneously-Held Preferences

Green and Hojman (2007) propose a third framework, which characterizes individual choices as the result of a compromise among simultaneously held and possibly conflicting sets of preferences. These preferences are aggregated into a decision based on a rule that can explain all observed outcomes for a given choice set. This framework is based on social choice theory, where the aggregation of conflicting individual preferences may violate the assumptions underlying the construction of the social welfare function. While this approach has some intuitive appeal, it is likely to be even more difficult to operationalize than the other frameworks. In particular, in the context of energy efficiency, the data requirements would be onerous.

Skepticism About Behavioral Welfare Economics

Some economists are skeptical about efforts to develop a theory of behavioral welfare economics. Gul and Pesendorfer (2008) view such efforts as misguided exercises and caution that using experienced utility for welfare analysis is a type of "social activism" that confounds a philosophical stance with an economic analysis. Smith and Moore (2010) argue that behavioral anomalies can be thought of as cognitive constraints added to the consumer's utility maximization problem, and thus are not behavioral failures. This suggests that when consumers appear to be inattentive or are using simplifying heuristics for making decisions, they are just optimizing under these constraints. Smith and Moore (2010) see this as a reason for continuing to rely on traditional welfare analysis, because consumers are still rational, optimizing, and processing information effectively. The deeper question here is whether the mere existence of cognitive constraints precludes there being any difference between decision and experienced utility.

We view the current state of the behavioral welfare economics literature as an important foundation for future research, but the existing theoretical work appears to be far from ready for use in practical policy analysis. Although attempts to develop a practical framework for policy analysis with behavioral failures are a step in the right direction, thus far they have avoided the fundamental question of how to reconcile revealed preference theory with the existence of behavioral failures (e.g., Allcott and Greenstone (2012) and Allcott, Mullainathan, and Taubinsky (2012)).

Energy Efficiency Policy

Economists have long recognized that implementing policies that are individually tailored in form and magnitude to address specific market failures can improve economic efficiency.

More recently, economists have noted that policies to address behavioral failures may also improve economic efficiency. This section discusses the implications of market and behavioral failures for energy efficiency policy and then examines empirical evidence concerning the effectiveness and cost of policies that have been used to promote energy efficiency in the United States.

Matching Policies to Market and Behavioral Failures

Determining the first-best policy intervention for each market or behavioral failure is not always straightforward. However, policies should always be tailored to the specific situation, with the benefits and costs of the policies assessed as fully as possible.

Policies to Address Market Failures

Unlike environmental and energy security externalities, for which a Pigouvian tax (or equivalent permit price) equal to the external cost is the clear first-best approach, the other potential market failures are more subtle. In fact, there may not always be a first-best approach that fully corrects for the externality. Nevertheless, there are still policies that can enhance efficiency. In the case of imperfect information, information provision is likely to be the most appropriate policy, but it will not be successful if consumers do not respond to it. The same is true for some principal-agent problems: with perfect information, landlords and tenants may be able to negotiate an appropriate contract (e.g., rewarding landlords who insulate buildings well). Credit constraints may be addressed through government financing programs, but such programs may not always be technically feasible or effective due to difficulties in targeting. To the extent that it can be quantified, learning-by-using is a classic positive externality, which lends itself to a subsidy. Finally, regulatory failures require improving the regulation.

Policies to Address Behavioral Failures

In the case of behavioral failures, policy is in order only if there is a deviation between decision utility and experienced utility. When such a deviation exists, providing information or changing the choice setting is generally the logical approach. To illustrate, consider self-control problems. If information is inexpensive and would clarify the trade-offs for consumers, then this could even be a first-best approach. However, it is not clear that information alone would necessarily be effective. For a second illustration, consider reference-dependent preferences, which may or may not result in a behavioral failure. When a behavioral failure is likely, policies that frame choices to focus on losses instead of gains may positively affect behavior and avoid the possibility of ex-post regret. If beliefs are biased and likely to lead to ex-post regret, information may reduce the extent of the bias. Similarly, if consumers are inattentive to energy efficiency as an attribute or use suboptimal decision heuristics, information provision may also be the first-best approach. Alternatively, if information provision is ineffective, changing the choice setting (i.e., using a nudge) may be a better approach.

The difficulty for policymakers lies in determining how to match the specific policy intervention (e.g., labels, certification, social norms campaigns, re-ordering of choices) to the specific behavioral failure. This difficulty is exacerbated by the many possible approaches to presenting information. More research is needed that closely examines both the information provision context and the behavioral failure.

When neither information provision nor a nudge is feasible, the focus shifts to second-best policies: product standards and subsidies for energy efficient products. Both of these policies have major shortcomings when consumers are heterogeneous. When energy use is heterogeneous, product standards may lead to over-investment in energy efficiency by those who do not plan to use the product much (Hausman and Joskow 1982). When there is heterogeneity in behavioral failures (i.e., some consumers optimize to a greater degree than others), some consumers may be over-subsidized, resulting in a deadweight loss. Allcott, Mullainathan, and Taubinsky (2012) suggest addressing this issue through behavioral targeting, which focuses policies on those consumers who are the most likely to systematically misoptimize. Behavioral targeting is conceptually similar to the Camerer et al. (2003) proposal for "asymmetric paternalism" (i.e., crafting policies that create large benefits for those who make errors but cause little or no harm to those who do not). This suggests that if policymakers have information on the nature and degree of behavioral failures, then in theory such targeting could result in a first-best outcome.

Empirical Evidence

We next examine empirical evidence concerning the three primary types of policies that have been used to promote energy efficiency: information strategies, economic incentives, and energy efficiency standards. Our focus is on evidence from the United States, but we discuss several international studies as well.

Information Strategies

Information strategies have long been used by utilities to provide technical assistance to firms and low- or no-cost energy audits to households. Several studies (e.g., Stern (1985), Stern and Aronson (1984), and Abrahamse et al. (2005)) have found that by themselves, information programs that identify energy saving investments and behavior changes have limited effects on energy consumption. In contrast, Anderson and Newell (2004) focused on industrial energy audits and found that firms did respond to the information provided by the audits, adopting roughly half of the audits' recommendations.

Product labels have also been widely used in the United States. Federal labeling policies include the Energy Guide Labeling program for new appliances and the fuel economy labels for new cars. Recently, New York City, San Francisco, Philadelphia, Seattle, and Washington, DC have adopted public disclosure rules about energy use in commercial buildings that exceed a size threshold; California and Washington State require disclosure of energy use for large commercial buildings when they are sold.[8] Another labeling approach is the federal Energy Star certification program, which allows the Energy Star label to be displayed on products (or homes and commercial buildings) that meet or exceed certain levels of energy efficiency. Houde (2013) examines the welfare effects of Energy Star certification and finds that while the program may have positive net benefits, it also has the unintended consequence of crowding-out other energy saving activity.

Some programs leverage social norms by providing consumers with information about their energy consumption relative to their peers along with suggestions for reducing energy use, including investing in energy efficiency. Schultz, Khazian, and Zaleski (2008) show that combining social norms messaging with energy savings tips reduces energy consumption. Allcott (2011) finds that social norm experiments conducted by the marketing company OPower throughout the United States reduced energy consumption by 2 percent on average, roughly equivalent to an 11-20 percent increase in energy prices. Costa and Kahn (2010) examine a subset of OPower programs in Sacramento, California and find that responses to these environmental nudges vary with political ideology. Ayres, Raseman, and Shih (2009) also find that leveraging social norms substantially reduces consumption, with a particularly strong effect on heavy energy consumers.

Economic Incentives

Financial incentives are commonly used to encourage consumers to invest in energy efficient products. Subsidies may take the form of rebates, tax incentives, or low-cost loans for

[8] Information about disclosure programs is available at http://www.energystar.gov/ia/business/government/State_Local_Govts_Leveraging_ES.pdf.

the purchase of energy efficient durables. Financial incentives are sometimes also used to encourage the development of energy efficient technologies (Gillingham, Newell, and Palmer 2006). Combinations of fees and rebates based on the efficiency of the product -- called feebates -- have been implemented for new vehicles in Canada and France, and have been discussed in the United States (Greene 2009; Greene et al. 2005; Johnson 2006).

There continues to be debate about whether recent subsidies for energy efficient products are welfare improving and how much they reduce energy use. Subsidies require a funding source, often from a distortionary tax, which implies a loss in economic efficiency. Subsidies can also lead to a rebound effect, which reduces energy savings. The evaluation of subsidy programs is further complicated by inframarginal consumers, often referred to as *free riders*, who avail themselves of the subsidy but would have bought the efficient product without the program (Joskow and Marron 1992). On the other hand, consumers called *free drivers* may purchase the energy efficient product because the existence of the rebate raised their awareness (Blumstein and Harris 1993; Eto et al. 1996; Geller and Attali 2005).

Most of the empirical literature on financial incentives has focused on utility energy efficiency programs, which typically combine information provision with rebates and other financial incentives. The evidence has been mixed. Several recent studies that analyze the cost-effectiveness of past programs (Arimura et al. 2012; Auffhammer, Blumstein, and Fowlie 2008; Loughran and Kulick 2004) generally find that the cost per kilowatt hour saved is greater than the (low) ex ante cost estimates by utilities and advocates. However, Auffhammer, Blumstein, and Fowlie (2008) and Arimura et al. (2012) find that the differences between their estimates of cost effectiveness and those reported by utilities are not statistically significant. Rivers and Jaccard (2011) find that energy efficiency program spending had no effect on electricity demand growth in Canada.

Energy Efficiency Standards

Although they are considered to be a second-best policy, energy efficiency standards tend to be one of the most politically feasible (and thus most popular), policy instruments used to promote energy efficiency. In the United States, there are national energy efficiency standards for nearly all major appliances, and some states have even stricter standards for certain appliances. Corporate Average Fuel Economy (CAFE) standards impose a minimum fleet-wide average fuel economy for new vehicles and building energy codes place minimum standards on the efficiency of newly constructed (and in some cases retrofitted) buildings.

The empirical literature on energy efficiency product standards is remarkably thin. Estimates of the energy savings resulting from appliance standards are typically based on ex ante engineering models and do not account for the effects of limiting choices on consumer surplus (Gillingham, Newell, and Palmer 2006). These ex ante studies also generally fail to consider rebound effects on energy use, although studies suggest that these effects may be small in many contexts (Davis 2008; Dumagan and Mount 1993).

There is, however, a growing literature that analyzes how CAFE standards affect energy use and welfare in the United States. Most economic studies assume away behavioral failures and generally find that a major tightening of CAFE standards leads to large welfare losses (Austin and Dinan 2005; Goldberg 1998; Greene 1991; Kleit 2004). Jacobsen (2013) examines both the new and used vehicle markets, as well as the gasoline market, and finds that a gasoline tax has roughly one-sixth the welfare cost of CAFE standards. In contrast, several recent studies that use simulation analyses to examine the economic efficiency of CAFE standards in the context of behavioral failures find that these standards increase economic efficiency when there are sufficient behavioral failures (Allcott, Mullainathan, and Taubinsky 2012; Parry, Evans, and Oates 2010).

A few empirical studies have explored the effects of building codes on energy consumption, with mixed results. In a cross-sectional analysis, Jaffe and Stavins (1995) find that building codes have no significant effect of on energy demand. Aroonruengsawat, Auffhammer, and Sanstad (2012) find that building codes decreased per capita residential electricity consumption by 3 to 5 percent, while Jacobsen and Kotchen (2012) find electricity savings of about 4 percent. Costa and Kahn (2011) find that building codes affected residential electricity consumption in California after 1983 but not before.

Conclusions and Directions for Future Research

This article has reviewed the literature on the energy efficiency gap, a phenomenon so difficult to explain that it has also been called the "energy efficiency paradox." More than 30 years of literature suggests that consumers behave as if they have high discount rates, and recent engineering studies indicate a vast untapped potential for negative-cost energy efficiency investments. However, the true size of the energy efficiency gap remains unclear. A variety of explanations, such as hidden costs, exaggerated engineering estimates of energy savings, consumer heterogeneity, and uncertainty all suggest that measurement errors contribute to the observed gap.

Yet measurement errors alone are clearly not the only explanation. There is empirical evidence that market failures such as asymmetric information and principal agent problems create a difference between the privately chosen and the socially efficient levels of energy efficiency. Moreover, there is growing evidence that behavioral anomalies may influence investment decisions, and such anomalies, ranging from self-control problems to reference-dependent preferences to biased beliefs and inattention, are becoming a commonly cited explanation for the energy efficiency gap. Many of these anomalies can be thought of as the ramifications of consumers facing cognitive constraints and simplifying their decision process with heuristics. Empirically identifying these behavioral anomalies in the context of energy efficiency is important but extremely challenging. Equally important for policy is establishing the extent to which these behavioral anomalies are actually behavioral *failures* that lead to a deviation between decision utility and experienced utility. We believe this is a promising area for future economics research.

It is becoming increasingly clear that the apparent energy efficiency gap has multiple explanations whose relative contributions differ across groups of energy users and types of energy uses. For example, the price volatility of gasoline and electricity differs substantially and thus so does the value of waiting to invest. Credit constraints are more relevant to lower-income households' purchases of appliances than to wealthy households' purchases of new vehicles. Informational issues differ between more and less sophisticated energy consumers.

Although this heterogeneity in explanations poses challenges for policymakers, it also helps to reveal which policy interventions are most likely to be cost-effective. The literature clearly suggests that targeting policies toward specific market failures and behavioral failures will improve cost-effectiveness. Yet, in the context of behavioral failures, deeper questions remain about how to perform a proper behavioral welfare analysis. Recently-developed frameworks that incorporate behavioral failures into policy analysis are an important step forward, but do not adequately address these deeper issues. This current state of our knowledge leaves us uncomfortable with using these new frameworks to justify current and proposed policies. That said, in those situations where nudges can be used to promote energy efficiency, such as OPower's social norms messaging experiments, we see no reason not to pursue them.

Thus, the heterogeneity in explanations presents researchers with both an opportunity and a challenge. The opportunity is that much empirical research remains to be done to quantify the size and nature of the efficiency gap in different contexts; the challenge is overcoming the difficulty of performing such empirical research. The list of research opportunities includes: 1. More careful studies of the full costs of energy efficient investments to consumers and firms, which could help clarify the role of hidden costs in hindering technology adoption; 2. Stated preference surveys or experimental approaches, which could be used to study the opportunity cost of amenities lost when more efficient products (such as light bulbs) are substituted for others; 3. Better quantification of the consumer response to information, which could help reveal how information processing works in energy efficiency decisions and establish the first-best policy interventions to address behavioral failures.

A further challenge for researchers is that the generalizability of findings from one energy use and energy user context to other users and uses may be limited. This is exacerbated by the difficulty of obtaining the data necessary to better understand energy efficiency investment behavior and its implications for energy use. Greater cooperation between policymakers and researchers in the development of policy (including randomized policy experiments), the sharing of data, and the ex post analysis of policy effectiveness would lead to both a better understanding of the gap and better policy in the future. Neuroeconomics may help identify the *sources* of the behavioral anomalies by examining the cognitive processes that lead to undervaluation of future fuel savings and clarify when there is a true difference between decision utility and experienced utility. Finally, welfare economics research that focuses on energy efficiency could provide a framework for developing economically efficient policies to address behavioral failures.

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