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Hunt Allcott and Michael Greenstone

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Abstract

Many analysts have argued that energy efficiency investments offer an enormous “win-win” opportunity to both reduce negative externalities and save money. This overview paper presents a simple model of investment in energy-using capital stock with two types of market failures: first, uninternalized externalities from energy consumption, and second, forces such as imperfect information that cause consumers and firms not to exploit privately-profitable energy efficiency investments. The model clarifies that only if the second type of market failure cannot be addressed directly through mechanisms such as information provision, energy efficiency subsidies and standards may be merited. We therefore review the empirical work on the magnitude of profitable unexploited energy efficiency investments, a literature which frequently does not meet modern standards for credibly estimating the net present value of energy cost savings and often leaves other benefits and costs unmeasured. These problems notwithstanding, recent empirical work in a variety of contexts implies that on average the magnitude of profitable unexploited investment opportunities is much smaller than engineering-accounting studies suggest. Finally, there is tremendous opportunity and need for policy-relevant research that utilizes randomized controlled trials and quasi-experimental techniques to estimate the returns to energy efficiency investments and the welfare effects of energy efficiency programs.

JEL Codes: D11, D18, D61, D62, H23, L91, L94, Q41

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Hunt Allcott is Assistant Professor of Economics, New York University, New York City, New York. Michael Greenstone is 3M Professor of Environmental Economics, Massachusetts Institute of Technology, Cambridge, Massachusetts. Allcott is a Faculty Research Fellow and Greenstone is a Research Associate, both at the National Bureau of Economic Research, Cambridge, Massachusetts. Their e-mail addresses are <hunt.allcott@nyu.edu> and <mgreenst@mit.edu>.

Many analysts of the energy industry have long believed that energy efficiency offers an enormous "win-win" opportunity: through aggressive energy conservation policies, we can both save money and reduce negative externalities associated with energy use. In 1979, Pulitzer Prize-winning author Daniel Yergin and the Harvard Business School Energy Project made an early version of this argument in the book *Energy Future*:

> If the United States were to make a serious commitment to conservation, it might well consume 30 to 40 percent less energy than it now does, and still enjoy the same or an even higher standard of living . . . Although some of the barriers are economic, they are in most cases institutional, political, and social. Overcoming them requires a government policy that champions conservation, that gives it a chance equal in the marketplace to that enjoyed by conventional sources of energy.

Thirty years later, consultancy McKinsey & Co. made a similar argument in its 2009 report, *Unlocking Energy Efficiency in the U.S. Economy*:

> Energy efficiency offers a vast, low-cost energy resource for the U.S. economy—but only if the nation can craft a comprehensive and innovative approach to unlock it. Significant and persistent barriers will need to be addressed at multiple levels to stimulate demand for energy efficiency and manage its delivery . . . If executed at scale, a holistic approach would yield gross energy savings worth more than $1.2 trillion, well above the $520 billion needed through 2020 for upfront investment in efficiency measures (not including program costs). Such a program is estimated to reduce end-use energy consumption in 2020 by 9.1 quadrillion BTUs, roughly 23 percent of projected demand, potentially abating up to 1.1 gigatons of greenhouse gases annually.

In economic language, the "win-win" argument is that government intervention to encourage energy efficiency can improve welfare for two reasons. First, the consumption of fossil fuels, which comprise the bulk of our current energy sources, causes externalities such as harm to human health, climate change, and constraints on the foreign policy objectives of energy-importing countries. Second, other forces such as imperfect information may cause consumers and firms not to undertake privately profitable investments in energy efficiency. These forces, which we refer to as "investment inefficiencies," would create what is popularly called an Energy Efficiency Gap: a wedge between the cost-minimizing level of energy efficiency and the level actually realized. Yergin, McKinsey & Co., and other analysts have argued that this gap represents a significant share of total energy use: in their view, the ground is littered with $20 bills that energy consumers have failed to pick up.

The energy efficiency policy debate often comingles these two types of market failures—energy use externalities and investment inefficiencies—causing imprecision in research questions and policy goals. In this paper, we distinguish between the two market failures and clarify their separate policy implications. If energy use externalities are the only market failure, it is well known that the social optimum is obtained with Pigouvian taxes or equivalent cap-and-trade programs that internalize these externalities into energy prices, and that substitute policies are often much less economically efficient. If investment inefficiencies also exist, the first-best policy is to address the inefficiency directly: for example, by providing information to imperfectly informed consumers. However, when these interventions are not fully effective and investment inefficiencies remain, policies that subsidize or mandate energy efficiency might increase welfare. The central economic question around energy efficiency is thus whether there are investment inefficiencies that a policy could correct—in other words, "Is there an Energy Efficiency Gap?"

We examine two classes of evidence on the existence and magnitude of investment inefficiencies that could cause the Energy Efficiency Gap. First, we examine choices made by consumers and firms, testing whether they fail to make investments that would increase utility or profits. Second, we focus on specific investment inefficiencies, testing for evidence consistent with each. After presenting the evidence, we discuss policy implications. Throughout the paper, we highlight how the economics of energy efficiency connects to important questions in other applied micro fields, including behavioral economics, industrial organization, and development microeconomics.

Three key conclusions arise. First, although there is a long literature assessing investment inefficiencies related to energy efficiency, this body of evidence frequently does not meet modern standards for credibility. A basic problem is that much of the evidence on the energy cost savings from energy efficiency comes from engineering analyses or observational studies that can suffer from a set of well-known biases. Furthermore, even if the energy cost savings were known, energy efficiency investments often have other unobserved costs and benefits, making it difficult to assess welfare effects. This problem is general to other economic applications: in order to argue that an agent is not maximizing an objective function, the analyst must credibly observe that objective function in full. We believe that there is great potential for a new body of credible empirical work in this area, both because the questions are so important and because there are significant unexploited opportunities for randomized controlled trials and quasi-experimental designs that have advanced knowledge in other domains.

Second, when one tallies up the available empirical evidence from different contexts, it is difficult to substantiate claims of a pervasive Energy Efficiency Gap. Some consumers appear to be imperfectly informed, and the evidence suggests that investment inefficiencies do cause an increase in energy use in various settings. However, the empirical magnitudes of the investment inefficiencies appear to be smaller, indeed substantially smaller, than the massive potential savings calculated in engineering analyses such as McKinsey & Co. (2009).

Third, because consumers are quite heterogeneous in the degree of their investment inefficiencies, it is crucial to design targeted policies. Subsidizing energy efficient durables, for example, changes relative prices for all consumers. While this policy will increase welfare for some consumers, such benefits must be traded off against distortions to consumers not subject to inefficiencies. Policy evaluations must therefore consider not just how much a policy increases energy efficiency, but what types of consumers are induced to become more energy efficient. Welfare gains will be larger from a policy that preferentially affects the decisions of consumers subject to investment inefficiencies.

Background Facts on Energy Demand

Overview of Energy Demand and Energy Efficiency

Table 1 presents the breakdown of total energy demand across the sectors of the U.S. economy. Much of our discussion focuses on household energy use and personal transportation instead of commercial and industrial energy use, because these are areas where inefficiencies of imperfect information might be more severe. In 2007, the average U.S. household spent $2,400 on gasoline for their autos and another $1,900 on natural gas, electricity, and heating oil (U.S. Bureau of Labor Statistics, 2007). Of this latter figure, heating and cooling are the most significant end uses, which suggests that they may also be the areas where energy conservation could have the largest effect.

The smaller the variance in energy costs across products relative to the total purchase price, the more likely it is that consumers will choose to remain imperfectly informed about, or inattentive to, these costs (Sallee, 2011). Figure 1 shows the lifetime energy cost of a selection of energy-using durables, discounted at 6 percent over each good's typical lifetime, as well as the ratio of energy cost to the purchase price. For example, if gasoline costs $3 per gallon, lifetime gasoline costs are $19,000 for a typical pickup truck, or 83 percent of the purchase price, and $10,000 for a relatively energy efficient sedan, or about 66 percent of purchase price. Typical lifetime energy costs are five times greater than purchase prices for air conditioners and 12 times greater for incandescent light bulbs, but only about one-third of purchase price for a typical refrigerator.

The most aggregate measure of energy efficiency is the ratio of GDP to total energy use, with different energy sources combined using common physical units. As shown in Figure 2, U.S. "energy productivity" per unit of GDP is 2.4 times higher than in 1949. Various factors drive this continual improvement, including compositional changes in the economy toward less-energy-intensive industries, energy efficiency policies, and other forces that drive total factor productivity growth. Energy prices also induce factor substitution and technical change: the figure suggests this effect, showing that the fastest improvements in energy productivity were in the 1970s and the most recent 15 years, both periods of relatively high energy prices. The figure also shows that U.S. energy productivity has grown faster than total factor productivity since the beginning of that data series in 1987, meaning that through some combination of directed technical change and factor substitution, the United States is economizing on energy faster than it is economizing on other factors. The U.S. economy is more energy intensive than other OECD countries, although it has improved more quickly since 1980, and less energy intensive than the set of low- and middle-income countries. In sum, the U.S. economy is progressively becoming less energy intensive, although this is uninformative about whether the United States is at or near the economically efficient level of energy efficiency.

Energy Efficiency Policy in the United States

The United States has enacted a wide array of policies to encourage energy efficiency, many of which were originally promulgated during the energy crises of the 1970s. Table 2 presents the most significant of these policies, along with some measure of their annual costs. Auto industry policies include: Corporate Average Fuel Economy (CAFE) standards, which require that the new cars and trucks sold by each auto manufacturer meet a minimum average rating based on miles-per-gallon; tax credits of up to $3,400 for hybrid vehicle buyers; and "gas guzzler taxes" ranging from $1,000 to $7,700 on the sale of passenger cars with low fuel economy. There are a series of national-level minimum energy efficiency standards for household appliances, such as refrigerators, air conditioners, and washing machines. Additionally, many states have building codes that encourage energy efficiency by, for example, stipulating minimum amounts of required insulation. Furthermore, electricity bill surcharges fund billions of dollars of utility-managed "demand-side management" programs, which include subsidized residential and commercial energy audits, energy efficiency information provision, and subsidies for energy efficient appliances and other capital investments.

"Weatherization" is frequently used as a general term for a set of residential energy efficiency investments primarily including wall and attic insulation, improved heating, ventilation and air conditioning systems, and "air-sealing," which reduces the leakage of hot or cold outside air. Through the Weatherization Assistance Program, the federal government transfers $250 million annually to state agencies to weatherize approximately 100,000 low-income homes. Weatherization funding grew significantly due to the 2009 American Recovery and Reinvestment Act. In total, that legislation and related economic stimulus bills included $17 billion in energy efficiency spending, including non-low-income weatherization programs, automobile and appliance cash-for-clunkers programs with energy efficiency requirements on new models, and other grants to state programs.

In this paper, the phrase "energy efficiency policies" refers to this set of subsidies and standards that directly encourage investment in energy efficient capital stock but do not directly affect energy prices. Although gasoline taxes, cap-and-trade programs, or other policies that affect energy prices will of course also increase investment in energy efficient capital stock, these policies that act through energy prices are conceptually distinct in our policy analysis.

A Model of Investment in Energy Efficiency

The basic economics of energy efficiency are captured by a model in which an agent, either a profit-maximizing firm or utility-maximizing consumer, chooses between two different versions of an energy-using durable good such as an automobile, air conditioner, or light bulb.[1] This setup can also represent a choice of whether to improve the energy efficiency of an existing building, for example through weatherization. In the first period, the agent chooses and pays for capital investments. In the second period, the consumer uses the good and incurs energy costs.

The two different goods are denoted 0, for the energy inefficient baseline, and 1, for the energy efficient version. They have energy intensities e_0 and e_1, respectively, with $e_0 > e_1$. The energy efficient good has incremental upfront capital cost $c > 0$ and unobserved incremental opportunity cost or utility cost ξ. The variable ξ could either be positive (an unobserved cost) or negative (an unobserved benefit). The private cost of energy is p, and the risk-adjusted discount rate between the two periods is $r > 0$. The variable m depends represents an agent's taste for usage of the durable good; a high m reflects an air conditioner user in a hot climate or a car owner who drives a long way to work. The variable m is implicitly a function of energy prices: as energy prices rise, the cost of utilization increases, so utilization decreases. We index m_i to explicitly recognize that it varies across agents, although in practice ξ and p will also vary.

In the basic case, an agent's willingness-to-pay for the energy efficient good is the discounted energy cost savings net of unobserved costs. Agent i will choose the energy efficient good if and only if willingness to pay outweighs the incremental capital costs:

$$pm_i(e_0 - e_1) / (1 + r) - \xi > c. \qquad (1)$$

[1] The model presented here is an adaptation of the model in Allcott, Mullainathan, and Taubinsky (2011). It resembles a generalized Roy model. It abstracts away from factors which may be relevant in some settings, including the irreversibility of some energy efficiency investments and uncertainty over energy costs (Dixit and Pindyck, 1994; Hassett and Metcalf, 1993) and explicit models of imperfect information in the purchase or resale of the good.

To capture the essence of the Energy Efficiency Gap, we introduce the parameter γ, which is an implicit weight on the energy cost savings in the agent's decision. Now, the agent chooses the energy efficient good if and only if:

$$\gamma p m_i(e_0 - e_1) / (1 + r) - \xi > c. \qquad (2)$$

For the purpose of determining the effects of subsidizing the energy efficient good, the γ parameter is a sufficient statistic for all investment inefficiencies. As we will discuss later in more detail, there are several distinct types of investment inefficiencies. First, agents may be unaware of, imperfectly informed about, or inattentive to energy cost savings. Second, agents may be themselves perfectly informed but unable to convey costlessly the energy intensity e_1 of an improved house or apartment they are selling or renting to others. Third, credit markets may be imperfect, meaning that agents may not have access to credit at the risk-adjusted discount rate r. [2] The γ parameter is conceptually related to what others have called an "implied discount rate," which is the discount rate that rationalizes the tradeoffs that agents make between upfront investment costs and future energy savings.

It is often asserted that $\gamma < 1$, meaning that investment inefficiencies cause agents to value discounted energy cost savings less than upfront costs. Notice that when this is the case, some agents do not choose the energy efficient good despite the fact that this would be profitable at current energy prices. Formally, asserting that there is an "Energy Efficiency Gap" is exactly equivalent to asserting that there are investment inefficiencies and $\gamma < 1$. Of course, in some settings it might be that $\gamma > 1$.

Other than the investment inefficiencies captured by γ, the additional element of the "win-win argument" is that there are additional social costs from energy use that are not internalized into energy prices. We denote this uninternalized externality by φ. In the social optimum, the agent adopts the energy efficient good if:

$$(p + \varphi)m_i(e_0 - e_1) / (1 + r) - \xi > c. \qquad (3)$$

[2] Credit constraints are a frequently discussed investment inefficiency. Although we note the issue in theory, there is not much empirical evidence in the context of energy efficiency, so we will not discuss it further.

The social optimum differs from the agent's choice in the previous equation for two reasons. First, the allocation accounts for the externality φ. Second, the allocation is not affected by investment inefficiencies, so $\gamma = 1$.

Figure 3 illustrates the three cases. The figure's horizontal axis represents the quantity of the energy efficient good that is purchased, while the vertical axis shows the incremental costs and benefits of purchasing that good. The height of a demand curve at each point reflects some individual agent's willingness-to-pay from the left-hand side of a corresponding equation above. The agents on the left side of the figure, with higher willingness-to-pay, tend to have high usage m, low unobserved cost ξ, and high energy price p.

The lowest demand curve, denoted D, reflects the case in the second equation with both investment inefficiencies ($\gamma < 1$) and uninternalized energy use externalities. In this case, the market equilibrium is at point a, the intersection of demand curve D with incremental cost c. Demand curve D' reflects the case in the first equation with no investment inefficiencies, but energy still priced below social cost. Demand curve D'' reflects the social optimum in the third equation, where there are no investment inefficiencies and energy prices include externality φ. Adding a Pigouvian tax on energy consumption (based on the energy source's pollution content) increases willingness-to-pay more for the consumers on the left of the figure with higher utilization, so demand curve D'' rotates clockwise relative to demand curve D'. The first-best equilibrium is point d, where D'' intersects incremental cost c.

From a policy perspective, it is crucial to distinguish the two types of market failures, energy use externalities and investment inefficiencies. The reason derives from the general principle that policies should address market failures as directly as possible. If there are no investment inefficiencies but energy prices are below social cost due to uninternalized energy use externalities, demand is represented by D'. This causes a distortion both in the purchase and in the utilization of energy-using durables: for example, consumers buy too many gas guzzlers and drive them too much. A Pigouvian tax of amount φ on energy (on gas, in the example) would give both the socially optimal quantity demanded (q'') of the energy efficient good and the socially optimal utilization. By contrast, as long as utilization is not fully price-inelastic, a subsidy for the energy efficient good does not achieve the first best. While this could move quantity demanded to q'', consumers would not face the true social cost of energy when deciding how much to use the good: consumers would buy the right number of gas guzzlers but still drive them too much.

Many investment inefficiencies, on the other hand, distort purchases but not utilization. If there are investment inefficiencies but no uninternalized energy use externalities, the optimal corrective policy affects purchases, but not utilization. For example, Allcott, Mullainathan, and Taubinsky (2012) show that when consumers have homogeneous $\gamma < 1$ and vary only in utilization m_i, the first-best policy involves a subsidy for the energy efficient good.[3] In Figure 3, that optimal subsidy would move quantity demanded from q to q'. Notice that an energy tax could potentially also correct the investment inefficiency, giving the same marginal consumer at q'. However, as long as utilization is not fully inelastic, an energy tax that gives price above social cost (to correct the investment inefficiency), would cause consumers to reduce utilization below the first-best level: consumers would buy the right number of gas guzzlers and then drive them too little.

Putting these arguments together, when there are distortions from both uninternalized energy use externalities and investment inefficiencies, the first-best policy involves both Pigouvian taxes on energy and a second mechanism to increase quantity demanded of the energy efficient good. This second mechanism may be a subsidy for the energy efficient good, although as we will discuss later in the paper, heterogeneity in the investment inefficiency γ makes subsidies potentially less desirable.

How can this framework be used for cost–benefit analysis? Consider first adding the subsidy in isolation, without any Pigouvian tax on energy. When there are investment inefficiencies, the original marginal consumer at quantity q gains amount *af* from being induced to buy the energy efficient good. In fact, there are allocative gains from inducing each of the consumers between q and q' to purchase the energy efficient good, as each of these consumers has benefits that are larger than incremental cost c. The total private welfare gains are illustrated by the triangle *abf*. If a Pigouvian tax on energy is added to this subsidy, then the total social welfare gain is illustrated by the triangle *adg*.

These benefits are then compared against the costs of the policy. A subsidy involves a transfer of public funds to consumers of amount *hbjk*, as illustrated by the shaded rectangle. If

[3] Heutel (2011) obtains a comparable result using a different model of investment inefficiencies.

those funds could otherwise be used to lower labor taxes, the deadweight loss of these taxes would be included as a social cost, along with any other costs of administering the subsidy.[4] Similarly, an information program that moved demand from *D* to *D*' would also increase private welfare by *abf*, and this welfare gain would be traded off with the costs of implementation. For any policy, it will be an empirical question whether the costs exceed the benefits, and whether the net benefits are larger than alternative policies. This approach to assessing net welfare benefits is the appropriate test of whether energy efficiency policies are socially beneficial when Pigouvian taxes are also available to correct energy use externalities.

To summarize, this section has analyzed two forces that can cause behavior to differ from the social optimum: energy use externalities and investment inefficiencies. If there are energy use externalities but no investment inefficiencies, ideally only Pigouvian taxes would be used. If there are investment inefficiencies, energy efficiency policies such as subsidies for energy efficient capital stock might have benefits that outweigh their costs. If there are both investment inefficiencies and energy use externalities, then Pigouvian taxes should be used in combination with some welfare-improving energy efficiency policy. The central economic questions are thus whether there are investment inefficiencies, and if so, whether the benefits of a corrective policy outweigh its costs.

In the next section, we will examine choices by consumers and firms to adopt or not adopt energy efficient technologies and attempt to infer whether there is an Energy Efficiency Gap. When there are no investment inefficiencies, agents' choices are governed by the first equation above, and unobserved factors such as costs ξ or utilization m can be inferred from their decisions. Some analysts have relied heavily on this framework in explaining away an apparent Energy Efficiency Gap, with an argument along the lines that "agents are well-informed, so if they are not energy efficient, then it must be that the unobserved costs of energy efficiency are large." The analysis is more difficult when there might be investment inefficiencies. In that case, we now must know everything about agents' objective functions to estimate the size of γ.

Three types of problems will pervade the analyses we review in the next section. First, factors that are difficult to observe or quantify, as denoted by ξ in our model above, will be potentially very relevant. Second, estimates of the net present value of energy cost savings are

[4] Analogously, a Pigouvian tax brings in public funds that can be used to lower labor taxes, which should be counted as an additional benefit (Bovenberg and Goulder, 1996).

often questionable. Depending on the setting, this could be because the analyst does not know the change in energy intensity ($e_0 - e_1$), the utilization m, or the appropriate discount rate r. Third, there is often substantial heterogeneity across consumers in utilization and unobserved costs, meaning that average returns for adopters might be uninformative about average returns for non-adopters or returns for the marginal adopter.

These empirical problems directly parallel other economic contexts. Consider, for example, the question of whether farmers in developing countries could profitably adopt agricultural technologies such as fertilizer and high-yielding variety seeds. These technologies have unobserved costs, such as increased labor inputs (Foster and Rosenzweig, 2010). It is difficult to know the resulting increase in profits without randomized controlled trials, as in Duflo, Kremer, and Robinson (2011). Also, the substantial heterogeneity in costs and gross returns means that the fact that adopters have high returns does not imply that non-adopters are foregoing a profitable investment (Suri, 2011).

Evidence on Returns to Energy Efficiency Investments

In this section, we analyze the evidence on whether consumers and firms leave profitable energy efficiency investments on the table. There are four categories of evidence: engineering estimates of returns to potential investments, empirical estimates of returns to observed investments, the cost effectiveness of energy conservation programs run by electric utilities, and estimated demand patterns for energy-using durables.

Engineering Estimates of Energy Conservation Cost Curves

While the McKinsey & Co. (2009) study quoted in our introduction has garnered substantial attention, it is preceded by a long literature that uses engineering cost estimates to construct "supply curves" for energy efficiency (for example, Meier, Wright, and Rosenfeld 1983; ACEEE 1989; Goldstein, Mowris, Davis, and Dolan 1990; Koomey et al. 1991; Brown, Levine, Romm, Rosenfeld, and Koomey 1998; National Academy of Sciences 1992; Rosenfeld, Atkinson, Koomey, Meier, Mowris, and Price 1993; Stoft 1995; Blumstein and Stoft 1995; Brown, Levine, Short, and Koomey 2001). The basic approach in such studies is to calculate the net present value of a set of possible energy efficiency investments given assumed capital costs, energy prices, investment horizons, and discount rates.

Across many studies from different industries and sectors, a common theme seems to emerge: large fractions of energy can be conserved at *negative* net cost. That is, the studies conclude that consumers and firms are failing to exploit a massive amount of profitable investment opportunities in energy efficiency. For example, a meta-analysis by Rosenfeld, Atkinson, Koomey, Meier, Mowris, and Price (1993) concludes that between 20 and 60 percent of total electricity use, depending on the study and the electricity cost assumption, can be conserved at negative cost. The McKinsey & Co. (2009) analysis quoted in our introduction suggests that 23 percent of U.S. non-transportation energy demand can be eliminated at negative cost. These engineering studies are a large part of the basis for the claims about the Energy Efficiency Gap.

However, it is difficult to take at face value the quantitative conclusions of the engineering analyses as they suffer from the empirical problems introduced in the previous section. First, engineering costs typically incorporate only upfront capital costs and omit opportunity costs or other unobserved factors (ξ in the model presented earlier). For example, Anderson and Newell (2004) analyze energy audits that the U.S. Department of Energy provides for free to small- and medium-sized enterprises. They find that nearly half of investments that engineering assessments showed would have short payback periods were not adopted due to unaccounted physical costs, risks, or opportunity costs, such as "lack of staff for analysis/implementation," "risk of inconvenience to personnel," or "suspected risk of problem with equipment."

Second, the engineering estimates of energy saved may be faulty. For example, in the context of home energy weatherization, Dubin, Miedema, and Chandran (1986), Nadel and Keating (1991), and others have documented that engineering estimates of energy savings can overstate true field returns, sometimes by a large amount. Even in the two decades since these studies, some engineering simulation models have still not been fully calibrated to approximate actual returns (Blasnik, 2010).

Empirical Estimates of Returns on Investment

Another approach to measuring the Energy Efficiency Gap is to use empirical energy use data to estimate the average returns for the set of consumers that adopt an energy efficient technology. Most of the evidence in this category analyzes the costs and benefits of the Weatherization Assistance Program, which is intended to be both a transfer to low-income homeowners and an energy efficiency investment with positive net returns. The typical empirical analysis compares natural gas billing data in the first year after the weatherization work was done to the year before, using either a statistical correction for weather differences or a non-randomly selected control group of low-income households. Schweitzer (2005) analyzes 38 separate empirical evaluations of weatherization projects from 19 states from between 1993 and 2005, reweighting them to reflect the observable characteristics of the national Weatherization Assistance Program. The average weatherization job costs $2,600 and reduces natural gas use by 20 to 25 percent, or about $260 per year.

As evidence on the Energy Efficiency Gap, such analyses again suffer from the problems introduced in the previous section. First, there are potentially substantial unobserved costs and benefits (the ξ in our model) from weatherization. Weatherization takes time, and for most people it is not highly enjoyable: the process requires one or sometimes two home energy audits, a contractor appointment to carry out the work, and sometimes additional follow-up visits and paperwork. Some benefits are also difficult to quantify: for example, weatherization typically makes homes more comfortable and less drafty. Furthermore, weatherization reduces the cost of energy services such as warmer indoor temperatures on a cold winter day, and this cost reduction causes people to increase their utilization of these services. (In the energy literature, this is called the “rebound effect.”) Measuring the change in energy use from weatherization without accounting for the utility gain from an increase in utilization of energy services understates the welfare benefits.

Second, the net present value of energy cost reductions is unknown. The empirical estimates are based on short-term analyses, and the persistence of returns over many years is rarely assessed.[5] If the $260 annual savings from Schweitzer (2005) are assumed to have a

[5] Sumi and Coates (1989) find 14 percent cumulative degradation of energy savings for Weatherization Assistance Program participants in Seattle after the first six years. Additional evidence using more recent data would be valuable, as would information on whether the rate of depreciation changes over time.

lifetime of 10 years or less, then weatherization does not pay back the $2,600 cost at any positive discount rate. At lifetimes of 15 or 20 years, the discount rate that equates future discounted benefits with current costs (the internal rate of return) is 5.6 or 7.8 percent, respectively. Furthermore, all of the estimates are non-experimental, and households that weatherize may also engage in other unobserved activities that affect energy use. This may be a larger concern with non-low-income weatherization programs, in which homeowners might be more likely to carry out renovations and energy efficiency work at the same time.

Third, the effects of weatherization on energy use are heterogeneous. For example, Metcalf and Hassett (1999) estimate the distribution of returns to attic insulation in the U.S. population using a weather-adjusted difference estimator with nationally representative panel data. The estimated median and mean returns on investment are on the order of 10 percent, and one-quarter of households had returns greater than 13.5 percent. This heterogeneity means that while estimates of average returns for adopters could in principle be meaningful in evaluating the costs and benefits of an existing program, a simple selection model like the one above would imply that the net returns for adopters overstate the net returns for non-adopters. On net, the available evidence seems inconsistent with significant investment inefficiencies in the context of weatherization.

Cost Effectiveness of Energy Conservation Programs

Many electric utilities run "demand-side management" programs, which largely consist of subsidies to households and firms to purchase energy efficient appliances, air conditioning and heating systems, and other equipment. If these programs can reduce energy use at less than the cost of energy, the argument goes, then there were investment inefficiencies, and the programs should be viewed as welfare-enhancing.

The simplest example of this approach is to divide the annual spending on these programs by utilities' estimates of electricity savings, as in Gillingham, Newell, and Palmer (2006). These estimated savings are typically from engineering estimates of electricity savings or non-experimental comparisons of energy use between program participants and non-participants. For 2009, U.S. electric utilities reported $2.255 billion in direct costs and 76.9 terawatt-hours of savings for demand-side management programs, according to the *2009 Electric Power Annual* (EIA 2010, tables 9.6 and 9.7). Dividing these two figures gives a cost effectiveness of 2.9 cents per kilowatt-hour (kWh). Friedrich, Eldridge, York, Witte, and Kushler (2009) also use utilities' estimates of electricity savings to calculate a cost effectiveness of 2.5 cents per kilowatt-hour.

Analyses such as these suffer from the same problems introduced in the previous section. First, the reported "costs" are typically costs to the utility, not including costs incurred by program participants, which may be almost as large (Nadel and Geller, 1996; Joskow and Marron, 1992; Eto, Kito, Shown, and Sonnenblick 1995; Friedrich, Eldridge, York, Witte, and Kushler 2009). Second, energy savings are estimated using engineering analyses or observational data, and it is difficult to establish a credible counterfactual level of energy use in the absence of the program. The most rigorous solution is to use randomized controlled experiments to evaluate demand-side management programs. The feasibility of this approach is demonstrated by recent experimental evaluations of programs that send letters that compare a household's energy use to that of their neighbors and provide energy conservation tips (Allcott 2011b; Ayres, Raseman, and Shih 2009).

The most advanced estimate in this literature is by Arimura, Li, Newell, and Palmer (2011), whose point estimates indicate that between 1992 and 2006, demand-side management conserved electricity at a program cost of 5.0 and 6.1 cents per kilowatt-hour, assuming discount rates of 5 and 7 percent, respectively.[6] If one further assumes, based on the analyses in the paragraph above, that additional costs to consumers might be 70 percent of program costs, one concludes that demand-side management programs have reduced energy use at an average cost of 5.0 x (1 + .70) = 8.5 cents/kWh or 6.1 x (1 + .70) = 10.4 cents/kWh, again using 5 or 7 percent discount rates, respectively. Comparing the investment cost per kWh conserved to the national average electricity price of 9.1 cents/kWh, the investments that occurred because of demand-side management programs were barely profitable at a discount rate of 5 percent, and barely unprofitable at a discount rate of 7 percent.[7] Arimura et al. (2011) estimate that these programs reduced 1–2 percent of national electricity demand. Given that only a small percent of total

[6] Arimura, Li, Newell, and Palmer (2011) also calculate cost effectiveness of 3.0 and 4.1 cents per kilowatt-hour using discount rates of zero percent and three percent, respectively. The authors focus on their results for a five percent discount rate.

[7] The text offers a back-of-the-envelope version of the more sophisticated calculation that should be done. One implicit assumption is that there are no consumers that are inframarginal to the demand-side management subsidies. If there are inframarginal consumers, then some of the program costs were in fact transfers, and the incremental investment costs induced by the demand-side management programs were smaller.

electricity demand was reduced at nearly zero excess profits, this evidence on demand-side management energy conservation programs does not suggest a pervasive Energy Efficiency Gap.

Tradeoffs between Durable Goods

The final way of determining whether there are profitable returns to energy efficiency investments involves estimating consumer demand for household appliances or automobiles. This approach typically uses a discrete choice model to estimate utility function coefficients on purchase price and on the present discounted value of energy costs. The estimated coefficient on energy cost should be the same as the estimated coefficient on price: that is, consumers should be indifferent between spending a dollar in present value on energy and a dollar in present value on purchase price. If the analyst's assumptions about discount rates, product utilization, and energy prices are correct, the ratio of these two coefficients is the γ in our model above.

In a seminal paper, Hausman (1979) estimated a discrete choice model using 65 observations of consumer choices between air conditioner models, which vary in upfront cost and energy efficiency rating. Hausman framed his analysis as an estimate of an "implied discount rate" that rationalizes the demand system by assuming $\gamma = 1$. Hausman's paper, along with Dubin and McFadden's (1984) analysis of households' choices between heating systems, was the state of the art in this literature for 30 years. Both papers find real implied discount rates of 15 to 25 percent, which is higher than returns on stock market investments but not much different from real credit card interest rates, which were around 18 percent.

However, such analyses suffer from the problems introduced in the previous section. First, unobserved product attributes (which are analogous to ξ in our formal model) complicate the cross-sectional econometric approach. The coefficient on the present discounted value of energy costs is biased if energy efficient products have better or worse unobserved characteristics. For example, automobile prices actually *decrease* in fuel economy, as the more energy efficient vehicles are smaller and often have fewer luxury amenities. Furthermore, product prices will often be correlated with unobserved attributes, giving the usual simultaneity bias in estimating price elasticity. As in Berry, Levinsohn, and Pakes (1995), this issue can potentially be addressed by using instrumental variables, but the instruments available may be dissatisfying.

Working papers by Allcott and Wozny (2011), Busse, Knittel, and Zettelmeyer (2012), and Sallee, West, and Fan (2011) use an alternative approach to address the problem of unobserved attributes. These papers take a panel of used durable goods, condition on product fixed effects, and test how the relative prices of more energy efficient vs. less efficient products change as energy price expectations vary over time. As an intuitive example of the identification strategy, notice that as expected gasoline prices rise, we should expect to see the market price of a three-year-old used Honda Civic increase relative to the price of a three-year-old Honda Accord, because the Civic is more energy efficient than the Accord. If market prices are not very responsive, this approach suggests that γ is small.

Relative to the other categories of evidence on the Energy Efficiency Gap, this approach is especially appealing because the fixed effects eliminate unobserved costs by construction. However, these analyses still suffer from the second problem, which is that they still require assumptions about the relevant discount rate, vehicle-miles traveled, and consumers' expectations of future gasoline prices (r, m, and p in our model above), and other factors. Allcott and Wozny's (2011) results tend to suggest that $\gamma < 1$, while Busse, Knittel, and Zettelmeyer's (2012) results tend not to support the hypothesis that $\gamma < 1$. The two analyses do agree that even if there is some investment inefficiency, the welfare losses would be relatively small. Allcott and Wozny show how to use discrete choice data to calculate the private welfare loss (equivalent to triangle *abf* in Figure 3 above). Their preferred estimate of γ suggests that investment inefficiencies in the auto market cause a welfare loss of about \$1 billion per year and an increase in gasoline consumption of about 5 percent. Busse, Knittel, and Zettelmeyer's results tend not to suggest that there are investment inefficiencies, implying that there would be zero welfare losses. In either case, the welfare loss and gasoline consumption increase appear to be small relative to the total market size.

Investment Inefficiencies That Could Cause an Energy Efficiency Gap

In the previous section, we examined evidence on whether consumers and firms fail to exploit profitable energy efficiency investments. In this section, we reverse the perspective by specifying particular investment inefficiencies that might cause underinvestment in energy efficiency and assessing the empirical evidence on their magnitudes.

Imperfect Information

Imperfect information is perhaps the most important form of investment inefficiency that could cause an Energy Efficiency Gap. Two basic models of imperfect information are most relevant. In one model, consumers and firms may be unaware of potential investments in energy efficiency. For example, homeowners may not know how poorly insulated their home is and may not be aware of the opportunity to weatherize. Similarly, factory managers may not know about a new type of machine that could reduce their energy costs.

An alternative model resembles Akerlof's (1970) "lemons" model. Buyers know that different products, such as apartments, commercial buildings, or factory equipment, have different levels of energy efficiency, but these differences are costly to observe. Thus, they are not willing to pay more for goods that are in fact more energy efficient. For example, a renter evaluating a set of different apartments may be aware that there is a distribution of wall insulation quality and thus of resulting heating costs, but the renter will not be willing to pay more for a well-insulated apartment without taking the time to inspect the insulation.

There are three approaches to assessing the magnitude of imperfect information in the context of energy efficiency. The first approach is to test for market equilibria consistent with imperfect information. Several recent projects used this approach in the context of renter-occupied vs. owner-occupied housing units. The theory is that because imperfectly informed renters will not be willing to pay more for energy efficient apartments, landlords have reduced incentive to invest in energy efficiency. Homeowners, on the other hand, do capture the benefits of improved energy efficiency, at least until they sell the property. Such a "landlord–tenant" agency problem implies that rental properties are less energy efficient than would be socially optimal.

As an example of this approach, Davis (2010) studies the market penetration of refrigerators, dishwashers, light bulbs, room air conditioners, and clothes washers that have earned the U.S. government's "Energy Star" designation, meaning that they are relatively energy efficient. Conditional on observable characteristics, renters are 1 to 10 percentage points less likely to report having Energy Star appliances. In percentage terms, these differences are large: they represent between 5.6 and 68 percent of the overall average Energy Star saturation rate. But because non-renters are themselves not very likely to own Energy Star appliances and because appliances make up only one-quarter of residential energy use, the differences in appliance ownership do not add up to a large difference in energy use: the author calculates that if renters had the same energy efficient appliance ownership rates as owner-occupied homes, total energy bills in rental homes would be 0.5 percent lower.

Heating and cooling represent close to one-half of residential energy use, meaning that insulation is a more important investment that could be subject to the landlord–tenant agency problem. Gillingham, Harding, and Rapson (2012) analyze data from California and show that when the resident pays for heating and cooling, owner-occupied dwellings are 13 to 20 percent more likely to have insulation than rentals, conditional on other observable characteristics of the property, occupant, and neighborhood. As in the Davis (2010) analysis, large percent differences do not translate into large increases in energy use: under the optimistic assumption that insulation reduces total energy demand by 10 percent, we can see that rental properties would use 1.3 to 2.0 percent less energy if insulated at the same level as owner-occupied properties.

Additional research in this area would be important to address problems of both internal and external validity. As both Davis (2010) and Gillingham, Harding, and Rapson (2012) note, conditional differences in appliance ownership between owners and renters are not ironclad causal evidence of a market failure, because preferences could vary in unobservable ways. Furthermore, even if estimates from California are internally valid, differences in policies and housing stock make it difficult to generalize nationwide. For example, California was a relatively early adopter of building codes, which means that more buildings in the state may now be insulated, and thus the difference between rental and owner-occupied properties may be smaller than in other states.

If these estimates are assumed to be causal and generalizable, how big is the investment inefficiency from the landlord–tenant agency problem? The magnitude is the number of affected households times the extent of the reduced energy efficiency. Of U.S. households, 29 percent are rental units where the renter pays energy bills (Murtishaw and Sathaye, 2006). Multiplying this figure by several percent of total energy demand, to approximate the magnitude of the inefficiencies estimated above, implies that the landlord–tenant information problem might increase total residential energy use on the order of 1 percent. Thus, while the empirical evidence points to some inefficiency, it explains only a very small fraction of the purported Energy Efficiency Gap.[8]

An additional example of testing for imperfect information using equilibrium outcomes is to examine whether information disclosure increases the elasticity of energy-saving technical change with respect to energy prices. The idea is that consumers who are better informed about energy use will be more responsive to energy price changes when choosing between models of an energy-using durable. Therefore, firms with better-informed consumers will be more likely to offer more energy efficient models as energy prices rise. Newell, Jaffe, and Stavins (1999) show that the mean energy efficiency of room air conditioners and water heaters was more responsive to energy prices after 1981 and 1977, respectively, the years when the federal government introduced energy efficiency labeling requirements for the two goods. While other factors might also have changed in these years, this finding suggests that the labeling requirements may have reduced the extent of imperfect information. However, this approach is not informative about the magnitude of any remaining investment inefficiency.

A second approach that can allow a direct assessment of the magnitude of imperfect information is to observe information sets through surveys. Turrentine and Kurani (2007) and Larrick and Soll (2008) use structured interviews and laboratory studies to show that consumers are not very good at calculating the gasoline costs for different automobiles. The 2010 Vehicle Ownership and Alternatives Survey (Allcott, 2011a, 2012) adds nationally representative evidence on how accurately consumers perceive the financial value of energy efficiency. The data suggest that consumers are indeed imperfectly informed: over half of Americans misestimate the gasoline cost differences between the vehicle they own and their "second choice vehicle" by more than 40 percent. However, the errors run in both directions. On average, consumers appear to either correctly estimate or slightly underestimate the energy cost savings from higher-fuel economy vehicles.

A third approach to assessing the magnitude of imperfect information is to test for the effects of information disclosure on purchase decisions. This approach has the benefit of being

[8] A related agency problem is that some landlords pay the utilities, while tenants set the utilization levels for appliances and heating and cooling equipment. This problem is a small, as only 4 percent of U.S. households are rentals with utilities included and demand for energy services is relatively inelastic. Levinson and Niemann (2004) estimate that energy costs are 1 to 1.7 percent higher when utilities are included in rent.

based on observed choices in the marketplace, instead of beliefs stated on a survey. We are not aware of any large-scale randomized evaluations of energy efficiency information disclosure.

Inattention

Interventions that resemble information disclosure might change the buying patterns of consumers who are already well-informed. For example, Chetty, Looney, and Kroft (2009) find that despite the fact that consumers are well-informed about sales taxes, posting information about sales tax amounts in a supermarket changes buying patterns. This finding suggests the existence of another type of investment inefficiency, which behavioral economists call inattention.

The psychology of inattention starts by recognizing that choice problems have many different facets, and some of these facets are less salient at the time of choice even if they are potentially important to the utility that will later be experienced. When buying printers, for example, we might focus on the purchase price and fail to consider that replacement ink cartridges make up the bulk of the total cost. Inattentive consumers are misoptimizing: they fail to recognize opportunities to save money by choosing products with lower ancillary costs. Research in a variety of other non-energy settings is suggestive of inattention (Hossein and Morgan 2006; Barber, Odean, and Zheng 2005; and Gabaix and Laibson 2006). It seems possible that some consumers might be inattentive to energy efficiency when purchasing energy-using durable goods.

Policy Implications

The available evidence on the size of an Energy Efficiency Gap is situation-specific, mixed, and often inconclusive. However, policymakers must make policy even in the absence of ironclad evidence.

If the goal is to achieve efficient economic outcomes, then market failures should be addressed as directly as possible. In response to energy use externalities, a Pigouvian tax gives the first-best outcome. If agents are imperfectly informed and the government has an inexpensive information disclosure technology, an information disclosure approach should be used. Formulating policy becomes more challenging if the first-best solutions are not possible—when information disclosure is not fully effective, or when a Pigouvian tax is not politically feasible because of aversion to new taxes or to policies that explicitly regulate greenhouse gases. In this section, we examine the effects of energy efficiency policies, considered as a second-best alternative.

Energy Efficiency Subsidies and Standards as a Second-Best Approach to Pollution Abatement

Until now, we have set aside the uninternalized energy use externalities and focused on investment inefficiencies. We now examine the converse: imagine a setting where no investment inefficiencies exist, but energy is priced below social cost (in our model, $\varphi > 0$). If Pigouvian taxes or cap-and-trade programs are politically infeasible, would energy efficiency subsidies and standards be a relatively promising approach to pollution abatement?

When no investment inefficiencies exist, energy efficiency policies such as subsidies for energy efficient durable goods and minimum energy efficiency standards would have larger welfare costs per unit of pollution abated compared to the first-best Pigouvian tax for several reasons. First, subsidies and standards change relative prices for all consumers equally, while the Pigouvian tax provides a larger incentive for consumers with higher utilization to choose energy efficient capital stock. Second, the first-best policy must impose the right price on the utilization decision, which only the Pigouvian tax does. Third, it is difficult to calibrate the stringency of an energy efficiency standard or subsidy precisely, meaning that it will likely generate more or less carbon abatement than a Pigouvian tax set at the level of marginal damages. Energy efficiency policies in different sectors can also be miscalibrated against each other, causing inefficiency due to unequal marginal costs of abatement.

Of course, if these three theoretical factors were small in reality, then energy efficiency policies might be a reasonable second-best substitute for Pigouvian taxes. Several analyses have simulated the relative cost effectiveness of particular energy efficiency policies relative to Pigouvian taxes. Jacobsen (2010), for example, simulates automobile supply and demand and shows that Corporate Average Fuel Economy (CAFE) standards have a welfare cost of \$222 per metric ton of carbon dioxide abated, compared to \$92 per ton for a gas tax that generates the same amount of abatement. Krupnick, Parry, Walls, Knowles, and Hayes (2010) come to a similar qualitative conclusion. They compare the cap-and-trade provisions of the proposed

Waxman–Markey climate change legislation to the legislation's energy efficiency provisions, which include standards for buildings, lighting, and appliances. The cap-and-trade, or an equivalent carbon tax, abates carbon dioxide at an upfront welfare cost of $12 per ton. Under the assumption that there are no investment inefficiencies, the energy efficiency standards are five times more costly, or $60 per ton. This significantly exceeds the United States government's estimated social cost of carbon dioxide emissions, which is about $21 (Greenstone, Kopits, and Wolverton 2011).[9]

These results forcefully argue that Pigouvian taxes or cap-and-trade programs are the most efficient way to address energy use externalities. Energy efficiency subsidies, CAFE standards, and other energy efficiency policies can also reduce energy use externalities, but in any settings where there are no investment inefficiencies, such policies will often impose a significantly larger cost on the economy per unit of pollution reduction.

Energy Efficiency Subsidies and Standards as a Second-Best Approach to Correcting Investment Inefficiencies

The United States has long required energy-use information disclosure: for more than 30 years, retailers have been required to display fuel economy ratings for new vehicles and energy cost information for home appliances. However, consumers may not notice, understand, or pay attention to this information. If information disclosure or other direct solutions to market failures are not fully effective, how useful are energy efficiency subsidies and standards as a second-best approach to addressing investment inefficiencies?

Allcott, Mullainathan, and Taubinsky (2011) analyze this question when consumers are inattentive to energy costs. As we discussed earlier, their model shows that energy efficiency subsidies can increase welfare and, when consumers are sufficiently homogeneous, the first-best can be obtained. The intuition is straightforward: if consumers and firms underinvest in energy efficiency, subsidizing or mandating them to invest more can increase welfare. However, any corrective policies must be properly calibrated. For example, the vast majority of benefits in the

[9] As we will argue in the next section, energy efficiency policies can increase welfare when there are investment inefficiencies. Krupnick, Parry, Walls, Knowles, and Hayes (2010) quantify this, showing that under an assumed level of investment inefficiencies, energy efficiency standards abate carbon at a cost of $7 per ton.

U.S. government's cost–benefit analysis of Corporate Average Fuel Economy Standards derive from the assumption that the regulation corrects consumers' inattention to energy efficiency when buying autos.[10] However, Allcott (2012), Allcott and Wozny (2011), Fischer, Harrington, and Parry (2007), and Heutel (2011) use different models to show that the current and proposed CAFE standards are much more stringent than can be justified by even worst-case estimates of investment inefficiencies.[11] Of course, if there are zero investment inefficiencies, then there are zero welfare benefits through this channel.

Heterogeneity in the investment inefficiency γ weakens the policy argument for subsidizing energy efficient goods, as Allcott, Mullainathan, and Taubinsky (2011) also show. In Figure 3 presented earlier, imagine that some consumers are on demand curve *D*' with $\gamma = 1$, while others are on demand curve *D* with $\gamma < 1$. Now, a subsidy moves the high-γ agents to point *z*, where they consume more energy efficiency than they would in the social optimum. This offsets the welfare gains from improving the decisions of the low-γ consumers. A key implication for policy analysis is that we must understand not just *how much* a policy increases sales of energy efficient goods, but *who* are the people induced to buy these goods. For example, even in a setting where the average consumer has $\gamma < 1$, energy efficiency subsidies might decrease total welfare if they are largely taken up by environmentalists and homeowners, who are more likely to be well-informed about energy efficiency and are not subject to a "landlord–tenant" agency problem.

This discussion highlights that energy efficiency policies are more likely to increase welfare if they target agents subject to the largest investment inefficiencies. Some existing policies do appear well-targeted. For example, households that use more energy than other

[10] For more background, see the federal government's Regulatory Impact Analysis of the 2012–2016 CAFE standards (National Highway Traffic Safety Administration, 2010) or the discussion in Allcott and Wozny (2011).

[11] Heutel calibrates the extent to which investment inefficiencies that cause consumers to undervalue gasoline costs by 30 percent decrease the average fuel economy of vehicles sold, relative to the optimum. An optimal policy response would therefore increase fuel economy by a corresponding amount. In Table 4, comparing column (1) to column (2) shows the effect of investment inefficiencies: 0.0439 gallons per mile (GPM) - 0.0426 GPM = 0.0013 gallons per mile. Thus, an optimal policy response decreases GPM by 0.0013 gallons per mile, or equivalently increases fuel economy by slightly more than 0.5 MPG. In Heutel's model, CAFE standards would not be justified by his assumed level of investment inefficiency, given that they require fuel economy to increase by much more than 0.5 MPG.

comparable households are more likely to have low-cost energy conservation opportunities of which they are unaware, and many U.S. utilities now target energy conservation information to these relatively heavy users (Allcott, 2011b; Ayres, Raseman, and Shih, 2009). “Smart meters” that record hourly consumption, which as described in a companion paper by Paul Joskow in this symposium are increasingly being deployed across the United States, also provide information useful for targeting. For example, utilities can now identify households that use more energy on afternoon hours of particularly hot days, suggesting that they have energy inefficient air conditioners, and send them information on new energy efficient models.

Aside from heterogeneity in the investment inefficiency, consumers and firms also have substantial heterogeneity in other factors that affect demand for energy and for energy efficient capital stock. For example, the mild climate of Los Angeles compared to the more extreme weather of Chicago means that there is substantial variation in utilization of air conditioners and heating equipment, and residential retail electricity prices vary across the country from 4 to 30 cents per kilowatt-hour. As a result, national-level minimum efficiency standards for home appliances seem likely to decrease welfare for subsets of consumers with low prices and utilization and could increase welfare for high-price and/or -utilization consumers with investment inefficiencies. Ideally, standards could vary geographically to take account of this, targeting consumers that may have the most to gain. For example, building codes in states with extreme weather often require more insulation than building codes in mild climates. On the other hand, home appliance standards are set at the national level, and appliance manufacturers and retailers operate nationwide. The benefits of heterogeneous standards must be weighed against the costs of regulatory complexity.

Conclusion

Since the energy crises of the 1970s, many have made the “win-win” argument for energy efficiency policy: subsidies and standards can both address investment inefficiencies in the purchase of energy-using durable goods and reduce externalities from energy use. However, a reliance on observational studies of variable credibility and the possibility of unobserved costs and benefits of energy efficiency make it difficult to assess the magnitude of the Energy

Efficiency Gap definitively. Nevertheless, the available evidence from empirical analyses of weatherization, demand-side management programs, automobile and appliance markets, the "landlord–tenant" agency problem, and information elicitation suggests that while investment inefficiencies do appear in various settings, the actual magnitude of the Energy Efficiency Gap is small relative to the assessments from engineering analyses.

Furthermore, it appears likely that there is substantial heterogeneity in investment inefficiencies across the population. Thus, targeted policies have the potential to generate larger welfare gains than general subsidies or mandates. Given this heterogeneity, policy analyses need to do more than assess how much a policy affects energy efficiency: they must also identify what types of consumers are induced to be more energy efficient.

We believe that this area is ripe for rigorous empirical research. Future research should utilize randomized controlled trials and quasi-experimental techniques to estimate the impacts of energy efficiency programs on heterogeneous consumer types and to address the challenges posed by unobserved costs and benefits. The economic insights from such research are potentially generalizable, and the policy implications are significant.

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Table 1: United States Energy Use		
By Sector (U.S. EIA 2011)		
Commercial		19%
Industrial		30%
Transport		29%
Residential		22%
	Residential Categories (U.S. EIA 2005)	
	Refrigerators	5%
	Air Conditioning	8%
	Water Heating	20%
	Space Heating	41%
	Other Appliances and Lighting	26%

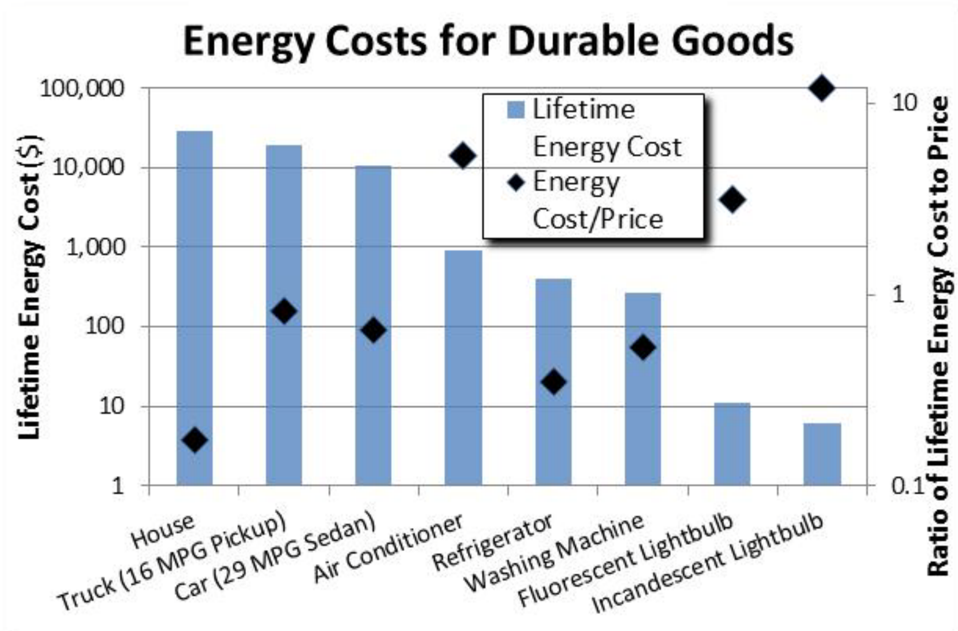
Source: Data are from U.S. Energy Information Administration (2005, 2011).

Table 2: Significant US Energy Efficiency Policies

Name	Years	Magnitude
Corporate Average Fuel Economy Standards	1978-	$10 billion annual incremental cost from tightened 2012 rule (NHTSA 2010)
Federal Hybrid Vehicle Tax Credit	2006-2010	$426 million total annual credit (Sallee 2010)
Gas guzzler tax	1980-	$200 million annual revenues (Sallee 2010)
Federal appliance energy efficiency standards	1990-	$2.9 billion annual incremental cost (Gillingham, Newell, and Palmer 2006)
Residential and commercial building codes	1978-	
Electricity Demand-Side Management programs	1978-	$3.6 billion annual cost (US EIA 2010)
Weatherization Assistance Program (WAP)	1976-	$250 million annual cost (US DOE 2011b)
2009 Economic Stimulus	2009-2011	$17 billion total (U.S. DOE 2011b)
Additional WAP funding		$5 billion
Recovery Through Retrofit		$454 million
State Energy Program		$3.1 billion
Energy Efficiency and Conservation Block Grants		$3.2 billion
Home Energy Efficiency Tax Credits		$5.8 billion total credit in 2009 (U.S. IRS 2011)
Residential and Commercial Building Initiative		$346 million
Energy Efficient Appliance Rebate Program		$300 million
Autos Cash for Clunkers		$5 billion

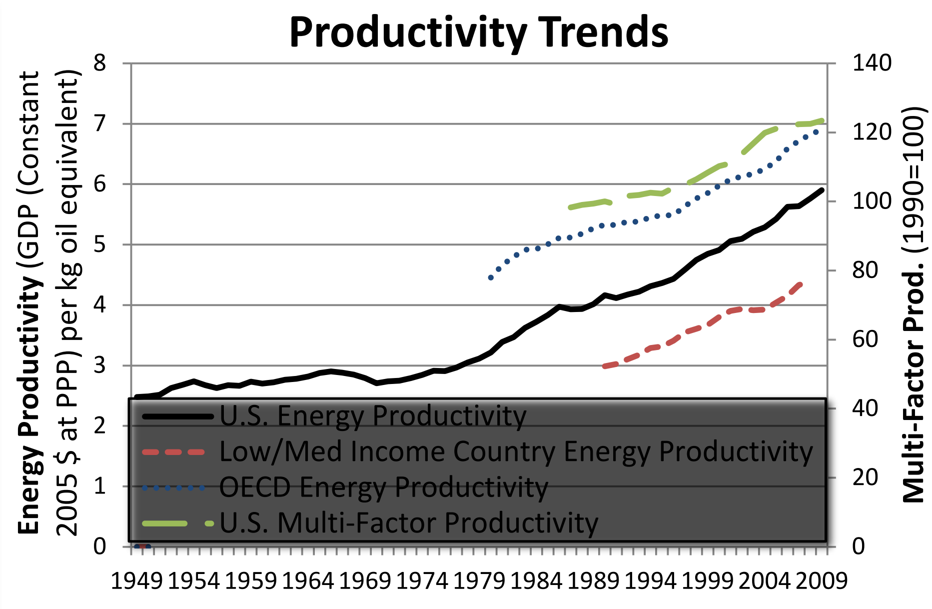
Source: Authors.

Figure 1: Energy Costs for Durable Goods



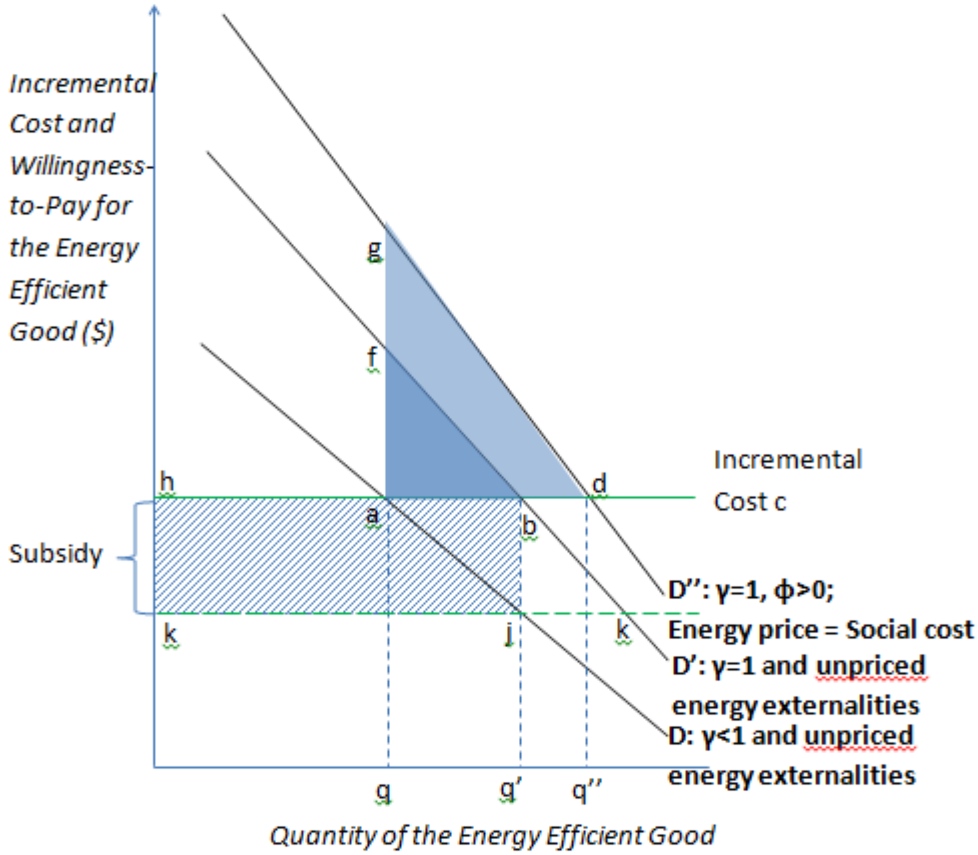
Source: Authors.

Figure 2: Productivity Trends



Note: PPP is "purchasing power parity." Multifactor productivity index equals 100 in 1990.

Figure 3: Demand for the Energy-Efficient Good



Source: Authors.