11. Economics of energy efficiency

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ABSTRACT for PUBLISHER (mandatory & no more than 150 Words)

The economics of energy efficiency have come a long way in the past two decades. This handbook chapter reviews major issues in the economics of energy efficiency, focusing on the most recent literature. We point out that much has been learned about potential mechanisms underlying the seemingly paradoxical gap between the observed energy efficiency and analyst-modeled optimal energy efficiency. While there is no simple consensus in the literature that applies in all contexts, we discuss how hidden costs and overestimated energy savings may account for some of the gap, but how behavioral anomalies and principal-agent issues (along with environmental externalities) may also play a role. We discuss policy implications along the way.

KEY WORDS for PUBLISHER (mandatory & no more than 6)
Energy efficiency, principal-agent problems, market failures, behavioral anomalies.
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1 Introduction

Over the past two decades economists have made great strides in improving our understanding of consumer behavior relating to energy efficiency, yet important policy-relevant questions remain. Energy efficiency is a crucial area for study for a variety of reasons. First, mitigating climate change in a low-cost manner is often considered among the most important issues of our time. If done cost-effectively, energy efficiency investments have the potential to be one of the lowest cost sources of carbon abatement. When the consumer's future energy bill savings, properly discounted to the present, alone outweigh the upfront cost, households can reduce their carbon emissions at zero or even negative cost. A common belief in the policy world (IEA, 2022) and in industry (McKinsey & Co, 2009) is that many such opportunities exist.

Energy efficiency could also enable decarbonization by reducing future energy demand, especially during peak hours (Boomhower and Davis, 2020). Indeed, many analysts see energy efficiency as a key component in any path to net zero by 2050. The International Energy Agency projects "efficiency improvements, combined with more robust materials efficiency and behavior change can amount to around 110 EJ, equivalent to total final energy consumption of China today" (IEA, 2022). If the energy transition to lower- and zero-carbon fuels increases the price of energy, this will also make energy efficiency all the more valuable.

Yet, there are challenges to achieving the rosy projections of energy use reductions. One of the most formidable challenges is the slow turnover of most energy-using durables. 55% of the buildings that will be in use in 2050 are already in place and more than a third of the cars, trucks, and heavy industrial facilities that will be in use in 2050 are expected to be added in the next two decades (IEA, 2022). Replacing capital prior to the end of its normal lifespan can be especially expensive, which raises important equity issues.

There are other key challenges to energy efficiency as a low-cost contributor to decarbonization. Realized savings from various energy efficiency programs often fall short of what is projected, so that benefits are lower than anticipated. In addition, there may be "hidden costs" that are not accounted for, such as search costs, time costs, differences in the quality of more-efficient goods, and in some cases behavioral "anomalies" drawn from research in behavioral economics. Research in recent years has worked hard to address these potential issues and, while there is no single consensus in the literature, there is solid evidence that consumers are leaving economically rational (i.e., from a private perspective) and socially valuable (i.e., in reducing pollution externalities) energy efficiency savings on the table. In this handbook chapter, we synthesize the evidence on the economics of energy efficiency. Because most of the evidence is from residential consumer decisions, we will focus our review accordingly, but we also bring in some evidence on commercial and industrial energy efficiency initiatives. We have aimed to cover the most crucial topics and the most recent literature on energy efficiency.

2 Economic Rationales for Energy Efficiency Policy

When choosing an energy-using durable good or equipment, energy efficiency is just one of many attributes that consumers consider. Perfectly rational consumers facing the decision of how much energy efficiency to acquire in the product purchase would weigh the additional upfront cost from the improved efficiency against the net present value of the expected future fuel savings. In this calculation, the net present value would be taken using the relevant discount rate that the consumer uses for all other investments. We can be more precise by putting this into mathematical terms. Perfectly rational consumers thus adopt a more energy-efficient product if the upfront cost K of the product exceeds the present discounted value of the expected future fuel savings, as follows:

$$K > E[\sum_{t=1}^{T} \delta_t P_t E_t]$$

where the expectation is taken over the distribution of future energy prices (P_t) and future energy savings in terms of KWh or fuel saved (E_t). The summation covers each period (e.g., month) t until the lifetime of the product and the future flows of fuel savings are discounted at the consumer's discount factor δ_t.

A common assumption is that consumer decisions about energy efficiency are made under complete information and a saturated product space that has products available with all combinations of attributes (including efficiency). In addition, in this simple model, there are no market failures or behavioral anomalies that could be influencing the consumer decision. Accordingly, under these conditions, the consumer choice of energy efficiency is optimal, as the consumer will weigh the upfront cost against the correctly estimated and discounted value of future fuel savings. Thus, there is no need for policy intervention unless there are other market failures at work, such as environmental externalities.

However, there is evidence that consumers do not always make decisions that appear to the analyst to be optimal. Specifically, it appears that in many contexts, consumers appear to *undervalue* (i.e., underestimate the value of) future energy bill or fuel savings from improved energy efficiency relative to other investments they make (Gillingham et al., 2006, 2009; Allcott and Greenstone, 2012; Gillingham and Palmer, 2014; Gerarden et al., 2015; Gillingham et al., 2018). Based on the framework above, this implies (1) underestimating the amount of energy savings from the product E_t, (2) underestimating energy prices P_t and thus the value of $P_t \cdot E_t$, or (3) discounting at a rate much higher than all other investments the consumer is making (i.e., using a biased δ_t). Much early work folded all possible underestimations into the discount rate, thus estimating a high "implicit" discount rate (i.e., low implicit discount factor) (Hausman, 1979), but the source of the underestimation may not be from discounting at all. More broadly, this phenomenon of consumers seemingly underestimating the expected future fuel savings is often called the "energy efficiency paradox" because consumers seem to be making decisions that are not in their own best interest. If this paradox is due to a market failure, this leaves open the possibility for policy to improve social welfare (Jaffe and Stavins, 1994; Gerarden et al., 2017).

A vibrant literature has developed to help explain this energy efficiency paradox. In some of the literature, environmental externalities are included as part of the energy efficiency paradox, and thus a failure to price the social cost of emissions from energy use leads to an underinvestment in energy efficiency relative to the socially optimal level of investment. But this would not explain consumers making decisions that appear to go against their best interests. It is possible that the analysts are incorrect in their estimation of the future fuel savings. There is growing evidence that the savings projected by engineering analysts can over-estimate the realized energy savings from a broad range of energy efficiency programs, including weatherization and home retrofits (Fowlie et al., 2018; Allcott and Greenstone, 2017; Zivin and Novan, 2016; Papineau et al., 2023; Christensen et al., 2023b), appliance replacement programs (Houde and Aldy, 2017; Davis et al., 2014) and building codes (Levinson, 2016; Bruegge et al., 2019).

In circumstances where the true savings from energy efficiency improvements do not match the analysts' estimated savings, the "energy efficiency paradox" may be much smaller than policymakers have assumed. Further, there may be the hidden costs as mentioned above, such as the search costs and time costs, that analysts have ignored. Similarly, there may be behavioral responses to improved energy efficiency, such as a "rebound effect" that leads agents to use more energy services upon facing a lower cost of usage when the efficiency is improved. This would imply overestimated energy savings. Accounting for these factors could narrow or eliminate the gap between observed decisions and the analyst's modeled optimal decisions (note that sometimes this gap is termed the "energy efficiency gap"). If analyst errors explain the gap, then consumers may be fully rational and there may be no paradox at all.

In contrast, there are a variety of phenomena in behavioral economics that might lead to a systematic bias between observed consumer decisions and the optimal decision for the consumers (National Academies of Sciences and Medicine, 2023). These phenomena include limited attention (i.e., consumers only having capacity to focus on certain attributes), loss aversion (i.e., consumers are especially averse to not having the upfront investment paid off), biased beliefs, and heuristic decisionmaking (Gillingham et al., 2018; Gerarden et al., 2015). There may even be rational inattention, where consumers have finite cognitive processing capability and rationally choose what piece of information to draw upon in making decisions (Sallee, 2014; Maćkowiak et al., 2023).

These explanations from behavioral economics raise the possibility that the consumer decision utility differs from the experience utility, as discussed above, possibly providing a justification for policy to "correct" suboptimal decisions, much as pricing pollution can internalize pollution externalities. Benefit-cost analyses of energy efficiency regulations often rely heavily on counting the future energy bill or fuel savings from energy efficiency policies on the benefits side of the ledger, which is implicitly assuming some behavioral anomaly that leads households to make suboptimal decisions. Should this behavioral anomaly lead to a true difference between ex ante (decision) utility and ex post (experienced) utility, such policies have potential to improve economic efficiency.

There also may be market failures on the supply-side of energy efficiency programs, where, due to asymmetric information contractors exhibit moral hazard in the quality of their workmanship (e.g., energy efficiency contractors may "shirk" on performing high-quality work because the efficiency is unobserved). Considering worker incentives in the design of energy efficiency programs may help ameliorate these issues, for example, by using quality control inspections coupled with performance pay and training programs.

Another common motivation for energy efficiency policies is to improve equity by reducing the energy burden on disadvantaged populations. Such policies may or may not improve economic efficiency, but may have positive distributional consequences and may be politically attractive. We next turn to the evidence on the efficacy and cost-effectiveness of energy efficiency policies.

3 Evidence on Policy Efficacy and Cost-Effectiveness

We organize our review in this section based on the category of energy efficiency policy. We begin with residential retrofit and weatherization programs, which is an important set of policies that often provides free or heavily subsidized energy efficiency opportunities, in many cases to low-income households. We then discuss three broad categories of energy efficiency policies: rebates, information policies (including energy audits), and efficiency standards.

3.1 Residential Retrofit and Weatherization Programs

If done cost-effectively, home weatherization and appliance upgrades can be one of the lowest-cost means of achieving carbon reductions, potentially at zero or even negative cost. Yet recent findings that the savings from many retrofit programs fall short of engineering analyst projections (e.g., Fowlie et al., 2018) has caused some economists to call into question the efficacy of relying on these programs as a low-cost means to meet climate objectives. Therefore, an important policy question is whether changes can be made to how these programs are run to more reliably achieve energy savings that outweigh the upfront costs.

To explore this point, Christensen et al. (2023b) examined the causes of the performance wedge – the discrepancy between projections and realized savings – in the Illinois implementation of the U.S.'s Weatherization Assistance Program (WAP). They showed that engineering measuring and modeling bias in estimating the savings from the program and quality of workmanship account for the vast majority of the wedge, 41% and 43% respectively for a total of 84% of the difference between the programâs estimates and what was realized in practice. Further, they find that the rebound effect (i.e., consumers using more electricity after energy efficiency improvements because the cost of usage has declined) appeared to be a relatively small contributor to the wedge (6%), which is consistent with other analyses of the WAP (Fowlie et al., 2018; Pigg et al., 2014). The major best-in-class energy efficiency modeling tools are based on set of commonly-accepted structural engineering equations that have been shown to systematically over-estimate savings (Edwards et al., 2013; Sentech Inc, 2010; Navigant, A Guidehouse Company, 2020) and similar contractor incentive issues exist across most energy efficiency retrofit programs. Thus, the drivers of the wedge are likely similar across many applications. Indeed, in other contexts, researchers have found moral hazard and incentive problems can affect the quality of building retrofits (Giraudet et al., 2018; Blonz, 2018).

Because the wedge appears to be primarily due to modeling bias and issues with contractor workmanship, it may be possible to implement policies to alleviate these problems. Christensen et al. (2022) show that using a data-driven approach – rather than engineering equations that are not based on data reflecting actual outcome experience – to predict retrofit impacts based on previously realized outcomes can be more accurate than the status quo engineering models. Targeting higher-return interventions based on these predictions increases net social benefits from $0.93 to $1.23 per subsidy dollar spent. Allcott and Greenstone (2017) study two residential energy efficiency programs in Wisconsin and also find that targeting subsidies based on previously realized outcomes can be beneficial. Without targeting, subsidies reduce social welfare by $0.18 per dollar spent, obviously not the intended outcome. In contrast, perfectly targeted subsidies can increase welfare by as much $2.53 per subsidy dollar. Of course, it may be difficult in practice to perfectly target subsidies given uncertainties about behavior and information.

It may also be possible to develop policies to improve the quality of the work done by energy efficiency contractors. Blonz (2018) shows that the effect of poor quality work can be quite large in a major utlity program to replace inefficient refrigerators: "cheating" by contractors reduces welfare by average of $106 per refrigerator and leads the program to save only half as much electricity as when program guidelines are being followed. Without the principal-agent distortion (i.e., the electric utility is the principal who cannot fully monitor the contractors who are the agents), welfare could increase by $60 per appliance replacement under a low-income program in California. Christensen et al. (2023a) run a field experiment that provide performance bonuses for higher-quality work, showing that the bonuses can increase natural gas savings by 24% and generate more than $5 in social benefits per dollar spent.

These issues of modeling bias and work quality likely extend to building codes and new efficient housing, as well as in the commercial setting. These areas are ripe for future research to better understand the mechanisms leading to the wedge in several settings.

A separate issue relating to home weatherization and retrofits is the possibility of landlord-tenant principal agent issues, whereby a landlord may have limited incentive to invest in energy conservation if the tenant pays for the energy use. These are another type of principal-agent issue entirely distinct from the issues with contractor work quality mentioned above. There is some empirical evidence that landlord-tenant issues can be a problem based on data in the United States (Levinson and Niemann, 2004; Gillingham et al., 2012; Myers, 2020), Ireland Petrov and Ryan (2021), and France (Charlier, 2015). As discussed in these papers, an important consideration about landlord-tenant issues is that there must be some informational friction or myopic behavior by tenants that hinders landlords from recouping energy-saving investments in the rent. This is an area of inquiry that also warrants further exploration.

3.2 Rebate Programs

Rebate programs, which provide subsidies for the purchase of energy-efficient durable goods, such as air conditioners, heat pumps, and refrigerators, are a common policy instrument used to promote energy efficiency. Although these direct purchase subsidies are the focus of this section, it is important to note that many rebate programs fall under the auspices of broader utility 'demand-side management' (DSM) programs. DSM encompasses not only energy efficiency but also a variety of demand response methods aimed at reducing and/or shifting electricity consumption to different times (Warren, 2017; HAHN and METCALFE, 2016). For a more comprehensive examination of demand-side policies, see Warren (2019).

One important line of research on rebate programs focuses on quantifying the energy savings. Like weatherization programs, there is a strand of literature finding that actual savings from rebate programs have been falling short of projections. The most likely explanation for this is that when provided with a rebate, consumers appear to buy models that have more features, and thus may use more energy (Houde and Aldy, 2017; Davis et al., 2014). If consumers are purchasing items with more features upon receiving the rebate, there may be an energy savings loss, but a welfare gain. However, if the type of new appliance is standardized, upgrade programs have the potential to be cost-effective (Blonz, 2018).

There is also evidence that cost-effectiveness of rebate programs can be hindered by a high degree of free riders. Free riders are inframarginal consumers who would have adopted the energy-efficient products anyway without the rebates. Free-ridership is fundamentally an "additionality" concern, similar to concerns about carbon offsets and many other environmental programs (van Benthem and Kerr, 2013) because it implies that the rebates lead to fewer *additional* adoptions of energy-efficient products. There is some evidence that there is high free-ridership from energy efficiency rebate programs. For example, Boomhower and Davis (2014) finds that about half of consumers in a nationwide appliance replacement program in Mexico would have adopted an energy-efficient appliance anyway even without a subsidy. More effective targeting of rebates to consumers most likely to be marginal may be a potential path forward and a fruitful area for new research.

3.3 Information and Labeling

Based on the idea that there could be information market failures or behavioral anomalies influencing consumer choice relating to energy efficiency, policymakers around the world have developed energy efficiency information and labeling programs. Some of these programs inform consumers about the energy efficiency of the goods available for purchase to allow for more fully informed decisions. Other programs focus on labeling the most-efficient products in a product category to encourage consumers to adopt those products.

In the United States, there is the EnergyGuide labeling program, which provides estimates of the annual energy operating costs of appliances and similar energy-using durable goods. Programs like EnergyGuide may help inform consumers. One challenge to such programs is that there may be individual heterogeneity in consumers and the numbers listed on the EnergyGuide labels may be misleading to consumers who differ from the average consumer. And many consumers may be very different than the average. For example, Davis and Metcalf (2016) discuss how the EnergyGuide label uses a national average electricity price, which could induce consumers to ignore local electricity prices, which vary quite substantially across the United States. This leads to biased decisionmaking regarding energy efficiency. Some consumers would be given information leading them to over-invest in energy efficiency, while others would be given information leading them to under-invest.

To better understand exactly what information provision does, economists have run field experiments that randomly vary the information provided to consumers. Allcott and Knittel (2019) run two experiments that vary the fuel economy information provided to new vehicle shoppers and find no statistical or economic effect of the information variations on the average fuel economy of the vehicles purchased. Similarly, Allcott and Sweeney (2017) run an experiment that varies the information and sales incentives provided to consumers about the efficiency of lighting, and find zero statistical effect from each intervention and explain at most a small fraction of the low baseline market share for high efficiency lighting. This line of evidence suggests very little effect of variations in information provided to consumers on their behavior, although it is not clear if the minimal measured effect is a general result or is the result of the particular information provided to consumers or the particular context in which it is provided.

Rodemeier and Löschel (2022) shows that information provision can affect demand, but it need not increase demand for energy-efficient products. For example, this study finds that informing consumers that LED lighting saves 90% in annual energy costs (compared to incandescent lighting) increases LED demand. However, also informing consumers that the 90% energy savings corresponds to an average savings of only 11 euros per lightbulb raises demand for less-efficient lighting technologies. La Nauze and Myers (2023) actually test whether consumers optimally acquire information on energy costs and find that they do not in the context of light bulbs. This work suggests that information subsidies can dominate product subsidies for addressing mistakes in product choice due to information acquisition failures.

Economists have also examined energy efficiency audit and mandatory disclosure policies to see how provision of information can influence consumer decisions and market outcomes. Such policies have become prevalent in many jurisdictions, including European countries, states in the United States, and many U.S. municipalities. The results from analyzing these policies are somewhat mixed.

Eichholtz et al. (2013) examine the economic premium that green commercial buildings receive on the rental and sales markets and find that increased energy efficiency is fully capitalized into rents and asset values, which suggests that information on energy efficiency is being conveyed to the market. This would suggest that commercial building operators would have an incentive to invest in energy efficiency. However, Gillingham and Weber (2023) show that mandatory disclosure and audit policy for large commercial buildings in New York City led to cost-effective reductions in energy use, suggesting that building operators were not fully informed about energy efficiency prior to receiving the information in the audits . Of course, these two pieces of evidence may be consistent: building operators may not be fully informed about cost-effective energy efficiency investments, but the investments they do make are capitalized in the rental and sales prices.

In the residential market, the evidence is also mixed. Aydin et al. (2020) use data from the Netherlands on mandatory energy performance certificates and find that energy efficiency is already capitalized in residential home values so that the introduction of energy performance certificates (EPC) do not affect prices. In contrast, Frondel et al. (2020) find that home buyers in Germany reduce offer prices in response to disclosure of energy efficiency information and that this is particularly pronounced for those homeowners who would not disclose in the absence of the mandatory disclosure policy. Similarly, Myers et al. (2022) show that mandatory disclosure of energy efficiency does lead to greater capitalization of energy efficiency in home values in Texas, and, importantly leads to increased energy-saving investments–the primary goal of these types of policies. Cassidy (2023) finds that mandatory disclosure leads to an increased capitalization of features that buyers are less likely to observe, but has no influence on the capitalization of features that buyers typically observe.

The mechanisms behind these results may relate to the fact that mandatory disclosure reduces the amount of time homes for sale stay on the market (Aydin et al., 2019), but that disclosure is not always completely informative (Cornago and Dressler, 2020; Myers et al., 2022; Frondel et al., 2020). Indeed, Palmer et al. (2013) survey residential energy efficiency auditors and find that the audit industry is only partly filling the information gap because many homeowners do not understand audits. Consistent with this finding, Gillingham and Tsvetanov (2018) show that a small informational intervention can increase residential energy efficiency audit uptake.

Another mandatory disclosure policy is a policy that provides specific labels for high-efficiency products to provide information to consumers on the most-efficient products in each category. Outside of the United States, most labeling programs use a discrete scale, whereby high-efficiency appliances are given higher energy class "grades," such as the EU appliance labeling approach that labels the most-efficient appliances as "A" or "B." Schleich et al. (2021) finds that the labeling scheme increased sales of the highest-efficiency appliances. Further Faure et al. (2021) shows that a rescaling of the energy classes in 2021 (previously the top grade was "A+++" and it was changed to "A"), increased sales of "A" refrigerators by differentiating them more from others. Andor et al. (2020b) show that providing additional operating cost information further increases sales of the most-efficient appliances.

In the United States, the EnergyStar labeling program is the most notable program, which provides the EnergyStar label for products exceeding a single efficiency threshold. The evidence suggests that EnergyStar may increase demand for high-efficiency products on average, but may reduce demand for the very highest-efficient products (Datta and Filippini, 2016; Houde, 2018), likely due to the coarseness of the information on the label (i.e., how many categories of efficiencies are presented on the label). The coarseness of the label may also crowd out efforts to process more accurate but complex information by consumers (Houde, 2018). Furthermore, because the label varies by product category, there is only an imperfect correlation between receiving the label and product energy consumption, so the label is a highly imperfect proxy for a consumer's actual energy operating costs (Newell and Siikamaki, 2017). Surprisingly, there is little evidence that energy prices affect the market share of EnergyStar appliances, suggesting that the label may work through a different channel than consumers making financial calculations about energy savings (Jacobsen, 2015).

The EnergyStar label has also been shown to have effects on firm product choices. Houde (2022) shows that firms are strategic in product choices and extract consumer surplus associated with certified products by offering products that bunch at the certification requirement, differentiating certified products in the energy and non-energy dimensions, and charging a price premium on certified products. All of these responses to the EnergyStar certification can reduce consumer surplus.

3.4 Energy Efficiency Standards

The final major category of energy efficiency policies are product standards requiring a minimum level of energy efficiency for the products. Economists have been especially interested in whether minimum energy efficiency product standards or taxes on emissions are preferred as an approach to addressing market failures relating to energy efficiency. A core result that emerges throughout the literature is that whether a standard or a tax is preferred depends on whether consumers are fully informed and attentive (Hausman and Joskow, 1982). Of course, the optimal suite of policies could involve both a minimum product standard to address behavioral anomalies and a tax on emissions to address environmental externalities.

Much of the evidence on energy efficiency standards is focused on the very prominent minimum efficiency standards for light-duty vehicles, which are predominately passenger cars. In the United States, these standards are the Corporate Average Fuel Economy Standards (CAFE) promulgated by the U.S. Department of Transportation and the light duty vehicle greenhouse gas standards promulgated by the U.S. Environmental Protection Agency. The key question is whether consumers are fully attentive to future fuel savings from improved efficiency.

For light-duty vehicles, the evidence on whether consumers undervalue energy efficiency is mixed. In particular, the findings seem to largely depend on the type of variation in the data being used and, in some cases, on the exact assumptions made by the study. When variation in gasoline prices is used to estimate how consumers value vehicle energy efficiency (usually by examining how the cost of driving influences equilibrium prices), studies tend to find that consumers do not substantially undervalue consumer expectations of future fuel savings (Busse et al., 2013; Allcott and Wozny, 2014; Grigolon et al., 2018). However, studies using exogenous variation in fuel economy ratings (Gillingham et al., 2021) or variation in technology options determining vehicle fuel economy (Leard et al., 2017) tend to find evidence of substantial undervaluation of future fuel savings, perhaps due to limited attention or other behavioral anomalies. Other evidence suggests that consumers have biased beliefs about the costs of running a vehicle (Andor et al., 2020a). In sum, the economics literature is not conclusive, but suggests that there may be some undervaluation of future fuel savings–the assumption that drives the results of the agency regulatory benefit-cost analyses.

There is a growing economics literature about the economic efficiency of vehicle efficiency standards, which depends very much on the valuation of future fuel savings from energy efficiency improvements. While many questions remain, some work suggests that vehicle efficiency standards can be economic efficiency improving (Bento et al., 2018). But, details of the standards may render them much less economically-efficient than they could be, such as basing the standards on vehicle attributes (Ito and Sallee, 2018). Further, vehicle exhaust air pollution standards can improve social welfare, but are also much less efficient than they could be (Jacobsen et al., 2022).

Shifting to residential housing, there is solid evidence that homeowners are much more attentive to future energy bill savings from energy efficiency than renters, because of principal-agent issues, selection into renting, and the expected duration of occupancy (Myers, 2019, 2020). Houde and Myers (2021) and Houde and Myers (2019) elucidate how behavioral anomalies, such as limited attention, may vary across the population and using the average value may mask underlying differences. With heterogeneity in preferences across the population, an important finding emerges: standards reduce the variance in energy operating costs relative to taxes, which ameliorates distortionary effects.

White certificate schemes are another policy instrument that is fundamentally an energy efficiency standard. White certificates are tradeable certificates that are similar to permits in a tradeable permit scheme. There is a standard amount of energy use reductions required and the certificates are granted to entities, such as companies, that have to comply upon the completion of energy use reductions. Giraudet et al. (2012) argues that these schemes, used throughout Europe, have been reasonably cost-effective and efficiency-improving. Of course, in making this assertion, they are making the assumption that behavioral anomalies or organizational failures are distorting energy efficiency decisions. Major questions arise about the evaluation of the energy use reductions and the interactions between white certificate schemes and other policies, and this is another area primed for more research.

4 Conclusions

The past two decades have seen a remarkable amount of work pushing forward the frontier on the economics of energy efficiency. From this work, we have learned several key lessons. One major lesson is that behavioral anomalies are crucial to justifying energy efficiency policies based on net benefits. While there is some mixed literature on the extent to which there are behavioral anomalies that could be characterized as a market failure, there is clear evidence of such anomalies in at least some contexts. Yet other explanations for the seeming under-investment in energy efficiency clearly play a role in many contexts, including poor quality workmanship and modeled overestimates of energy savings. Understanding the mechanisms influencing the deviation between the modeled optimal decision and observed decisions is crucial for policy. The mechanisms may suggest alternative policy approaches to directly address the issue, including information provision or measures to ensure workmanship quality, or could point to less of a need for policy.

We have also learned that the exact magnitude of the pollution externalities, while secondary to behavioral anomalies, can make a very large difference to the net benefits of policies. For example, Christensen et al. (2023a) show clear evidence of overestimation of energy savings by engineering models used to assess the low-income focused Weatherization Assistance Program. But they also show that the magnitude of pollution externalities really matters for the overall welfare implications of the energy-efficiency program: if the Rennert et al. (2022) value of $185 rather than $50 per ton of carbon dioxide for the avoided marginal damages of pollution is used, the social net benefits would positive rather than negative. This does not overturn the point that the energy savings for this energy efficiency program were overestimated, but it does emphasize the importance of the magnitude of the pollution externalities for the overall welfare consequences of energy efficiency policies.

With more evidence on the heterogeneous impacts of energy efficiency policy, a ripe area for research is understanding how best to target incentives to consumers to achieve policymakers' desired outcomes. For example, if policymakers want to maximize energy savings per subsidy dollar spent, they will need to know ex ante which subsets of the population are most likely to be marginal to the subsidy and most likely to have large treatment effects. Another dimension policymakers might want to target is equity. An important area for research is to more deeply explore the equity-efficiency tradeoffs inherent in energy efficiency policies focused on disadvantaged communities, as many are. With increased concerns about environmental justice, there is much discussion about reducing energy burdens for disadvantaged households. Understanding both the economic efficiency consequences and broader equity/distributional consequences is important for policy, and yet we observe only a few papers in the economics literature moving in this direction.

There are also many other exciting areas for future research as technology is improving. There are major opportunities for energy efficiency programs that also enable remote management of heat pumps, electric water heats, and electric vehicles, potentially allowing for a lower-cost and more reliable electricity grid. Questions of whether improving the efficiency of one technology may lead to a path dependence that reduces the likelihood of technology advances in other technologies also arise. In sum, we see great potential for future research to further disentangle the energy efficiency paradox, shed new light on mechanisms, and explore compelling new technologies along with energy efficiency.

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