Mind the Gap? Critically Reviewing the Energy Efficiency Gap with Empirical Evidence

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Abstract

A large body of literature suggests that households could save money by increasing the level of energy efficiency of the energy-using durables they purchase – a so-called "energy efficiency gap". High implicit discount rates estimated from purchases of energy-using durables have generally been interpreted as evidence of such an energy efficiency gap. However, the "discounting gap" between econometrically estimated discount rates and risk-adjusted market interest rates commonly presented in the literature is caused by different factors not all of which portray privately suboptimal purchase decisions by households. In particular, the discounting gap overstates the size of an energy efficiency gap in the choice between efficient and inefficient durables because of estimation and interpretation flaws. This article reviews the factors potentially explaining the observation of a discounting gap in the purchase of energy-using durables. It separates the factors only contributing to a discounting gap from the ones causing an energy efficiency gap to reveal a discrepancy between the size of the estimated discounting gap and the empirical findings of privately inefficient behavior by households.

Keywords: Energy Efficiency Gap, Discounting, Purchase Decision, Behavioral Anomaly

1 Introduction

In many countries, production and consumption of energy yields negative externalities, such as climate change, nuclear disasters, or dependencies on fuel imports. The reduction of energy consumption is therefore a widespread policy goal. One possibility to achieve this goal without reducing utility from energy consumption is to increase the energy efficiency of energy-using durables in private households. Energy-using durables are defined as manufactured products, such as automobiles or household appliances, that can be used over a relatively long period.

From an economic perspective, the purchase decision for an energy-using durable is typically characterized by a trade-off between initial capital costs and long-term operating costs, as efficient products usually have higher capital costs and lower operating costs than inefficient products.[1] The purchase of an efficient product instead of an inefficient alternative providing the same level of energy service can thus be considered an investment in energy efficiency: Higher expenses today generate financial rents in the future in the form of lower energy costs. Broadly speaking, a purchase decision by a utility-maximizing household is economically optimal when total costs, i.e. capital costs plus lifetime operating costs, are minimized subject to an equivalent level of energy service provided. Wilson and Dowlatabadi (2007) explain such utility-based decision models and their importance in residential energy decisions. This article draws on their description of "rational" and "irrational" behavior: Rational actors have preferences over financial and non-financial outcomes that are ordered, known, invariant, and consistent. They seek to maximize expected utility, which is a construct that measures the preferences expressed for different outcomes occurring with a certain (or uncertain) probability. Individual choices violating one or more of the axioms of preferences on which expected utility theory is based are considered as irrational in normative terms.

Following Gerarden et al. (2015b), I provide a deliberately simple version of a cost-minimizing purchase decision for a household i in order to highlight the main features of the issue:

$$\underbrace{\min \text{Total Cost}}_{\text{objective}} = \underbrace{K(E)}_{\text{equipment purchase cost}} + \underbrace{O_i(e_i(E), p_i) \times D_i(r_i, T)}_{\text{discounted operating costs}} + \text{other costs} \tag{1}$$

The purchase cost K for any appliance is a function of the energy efficiency E of the appliance, where E denotes a normalized measure of energy input required to obtain a given energy service.

[1] The terms "efficient" and "inefficient" are used to describe the relative difference in energy efficiency between different appliances of the same product category.

A higher level of energy efficiency E denotes lower energy input needed to obtain the same level of energy service. Since the technological progress inherent in products with higher energy efficiency is costly, K is generally increasing in E, i.e. efficient products are usually characterized by higher purchasing costs $K(E)$. Operating costs O_i are a function of annual energy use e_i and energy price $p_{e,i}$. Annual energy use e_i is decreasing with the degree of energy efficiency E of a product. The discount factor D_i is a function of the discount rate r_i and the relevant time horizon T, i.e. the lifetime of the product. The term "other costs" subsumes other possible costs related to the purchase of an energy-using durable, such as the opportunity costs of adoption (e.g. search costs, implementation costs, etc.) or differences between efficient and inefficient products in the (perceived) quality of energy service provided.

Households commonly appear to refrain from investing in more energy-efficient durables, even if such investments would result in net monetary savings and thus be privately economically optimal (Chandler and Brown, 2009; EPRI, 2009; Granade et al., 2009; McKinsey & Company, 2009; National Academy of Sciences, 2009; Rosenfeld et al., 1993). In these cases, the present discounted value of future energy savings would exceed the higher upfront costs of investments in efficient equipment and appliances at current energy costs. Granade et al. (2009) estimate that the United States could reduce annual energy consumption by 23 percent by deploying an array of financially profitable energy efficiency measures, with the residential sector accounting for 35 percent of the end-use efficiency potential. The observation that households do not make all privately optimal investments in energy efficiency has led to the term "energy efficiency gap" (Hirst and Brown, 1990). By refraining from purchasing energy-using durables of higher energy efficiency, households seem to incur unnecessarily high total costs over the product lifetime – i.e. they fail to minimize total costs in Equation (1) (Howarth and Stanstad, 1995). The energy efficiency gap in purchases of energy-using durables is viewed as a purely economical, utility-based concept in this article: A rational, utility-maximizing household i is expected to minimize total costs according to Equation (1) in a choice of energy-using durables with different levels of energy efficiency E, leading to the privately optimal level of energy efficiency E^*. Any $E < E^*$ is not utility-maximizing, economically speaking irrational, and corresponds to an energy efficiency gap, because it entails excessive lifetime energy costs. Using the terminology of Jaffe et al. (2004), this corresponds to the notion of the "Economists' narrow optimum" for the energy efficiency gap, as it is confined to individual decision-makers and does not consider the broader social perspective.[2] This perspective is in line with a large share of the literature considering an energy efficiency gap in the choice of an inefficient appliance as opposed to the choice of an alternative, efficient appliance providing similar energy services. A different aspect of the energy efficiency gap not elaborated in this article is the *timing* of the purchase decision of an energy-using durable, i.e. at what point an aging, inefficient appliance is replaced.

Energy efficiency policy to reach the economists' narrow optimum benefits from a "win-win" argument: saving money for households who otherwise fail to minimize total costs by underinvesting in energy efficiency (i.e. an energy efficiency gap) and reducing externalities from energy use (Allcott and Greenstone, 2012). For energy policy purposes, it is of peculiar interest to locate this narrow optimum and identify measures to encourage its achievement. Potential policy measures to increase the level of energy efficiency beyond this point towards the social optimum leave the "win-win" territory, as they might be detrimental to the utility of some households. This raises the barrier for their political enforcement even though they could be legitimated by general welfare gains.

A common method to determine whether households reach the economists' narrow optimum of energy efficiency has been to examine the discount rates applied in the trade-off between equipment purchase costs and operating costs, using discrete choice models. For a utility-maximizing household acting according to Equation (1), it is possible to estimate implicit discount rates ϑ by applying revealed preference methods on actual purchase data of energy-using durables (Samuelson, 1938). The rate of time discounting implicitly applied by a consumer who is indifferent between an inefficient product L (with low purchase cost K_L and high operating costs O_L) and an efficient product H (with high purchase cost K_H and low operating costs O_H) is called the "implicit discount rate" ϑ. Epper et al. (2011) provide a simple stylized example of the method to estimate implicit discount rates (p.2): Suppose a consumer is indifferent between two products, an efficient product H with a purchase price p_H and running costs c_H, all accruing in $t = 1$, and an inefficient product L with price p_L and running costs c_L with $p_H > p_L$ and $c_H < c_L$. Assuming linear utility and equating the present value of total costs $p_H + c_H \exp(-\vartheta) = p_L + c_L \exp(-\vartheta)$ yields and implicit discount rate of $\vartheta = -\ln \frac{p_H - p_L}{c_L - c_H}$. Higher discount rates make the efficient product H less preferable,

[2]This is in contrast to a recent working paper by Gerarden et al. (2015a) who instead use the term "energy efficiency paradox" for the narrow optimum. They use the broader concept of social optimality to define the energy efficiency gap.

as the lifetime energy cost savings are discounted more heavily and thus carry a lower weight. High discount rates could thus be the cause for a low frequency of purchases of the efficient product H, and hence for an energy efficiency gap. I use the term "discounting gap" for implicit discount rates ϑ deviating from a market return available on investments with similar risks r_m: discounting gap $= \vartheta - r_m$. From an economic perspective, it is not rational for households to require a different rate of return for purchases of energy-using durables than they could attain for other investment opportunities of similar risk. Since higher discount rates lead to lower investments in energy efficiency, positive discounting gaps have commonly been interpreted as evidence of an energy efficiency gap (Howarth and Stanstad, 1995; Train, 1985).

This article critically comments on the popular notion to take a discounting gap as evidence of an energy efficiency gap by raising the following questions: Are the observed purchases of energy-using durables used to estimate implicit discount rates a valid measure for the utility of outcomes? Are the factors explaining a discounting gap also factors explaining an energy efficiency gap? In other words, are the estimates of a discounting gap solely driven by economically non-optimal (i.e. irrational), private utility-reducing behavior?

The article reviews the literature on the factors causing a discounting gap in the purchase of energy-using durables and divides them into three categories: objective factors, subjective factors, and confounding variables. Objective factors comprise classical market failures like imperfect information (e.g. with respect to the energy use of an appliance) or liquidity constraints and credit rationing that are beyond the decision process of the household and limit the choice set in Equation (1). Subjective factors influencing the outcome of Equation (1) include: limited attention; reference-dependence; hyperbolic time discounting; biased beliefs; decision heuristics; high rates of time preferences; and subjective risk and uncertainty considerations. The confounding variables subsume the "other costs" mentioned in Equation (1) that might contribute to a discounting gap if they are unobserved or unaccounted for in the discrete choice model used to estimate implicit discount rates. On the one hand, the objective factors and the subjective factors representing behavioral "anomalies" can lead households to make economically non-optimal, irrational purchase decisions. Hence, these factors can lead to the estimation of high implicit discount rates that correspond to an energy efficiency gap. On the other hand, high rates of time preferences, subjective risk and uncertainty considerations, and the confounding variables are rationally considered by households in their purchase decisions. Therefore, these rational factors might lead to the estimation of a discounting gap which overstates the energy efficiency gap.

Empirical evidence of the particular factors causing a discounting gap reveals a discrepancy between the claims of a sizeable energy efficiency gap – based on the estimates of a large discounting gap – and the empirical findings of privately inefficient behavior by households. While the energy efficiency gap in purchases of energy-using durables is likely smaller than commonly suggested, convincing evidence of its existence persists. Eliminating an energy efficiency gap is a desirable goal in order to reap the "win-win" benefits of energy efficiency improvements. The evidence of the causes of inefficient behavior presented in this article is helpful for policy purposes in order to design policy measures targeted at mitigating these causes.

The remainder of this article is structured as follows. Section 2 reviews the literature on a discounting gap in the purchase of energy-using durables and presents an overview of its potential explanations. Section 3 elaborates on the explanations for a discounting gap that represent economically non-optimal, irrational purchase decisions and are thus part of an energy efficiency gap. Section 4 details the explanations of a discounting gap that are part of rational purchase decisions and should therefore not enter the conversation of an energy efficiency gap under the notion of the economists' narrow optimum. Section 5 concludes and provides recommendations for future research and for energy policy.

2 Origin of the Discounting Gap

The probably most complete review of empirical estimates of discount rates from many different contexts is provided by Frederick et al. (2002). They show that observed discount rates tend to be very high, often exceeding market interest rates by substantial margins, and vary considerably across individuals and across studies. Furthermore, Frederick et al. (2002) document that discount rates exhibit a magnitude effect, i.e. discount rates for small amounts tend to be much higher than rates for large amounts. Finally, the observed discount rates are not constant but rather decline with the time horizon, i.e. near-present events tend to get discounted much more heavily than events in the remote future. This type of behavior has been labeled "hyperbolic discounting" because the discount function has a hyperbolic form, reflecting declining discount rates over time.

Concerning consumer choices of energy-using durables, empirical estimates of implicit discount rates date back to the seminal publication by Hausman (1979), who estimated households' implicit

Table 1: Estimated product-specific implicit discount rates in the purchase of energy-using durables p.a.

Category	Implicit Discount Rate
Space heating	2% – 36%
Air conditioning	3% – 29%
Refrigerators	39% – 300%
Lighting	7% – 182%
Automobiles	2% – 45%
Thermal insulation	10% – 32%
Water heating	24% – 243%

Sources: DEFRA (2010), Frederick et al. (2002), Train (1985).

discount rates in observed purchases of air conditioners using a discrete choice model, which is an application of utility theory. He found that individuals on average use a discount rate of about 30 percent in making the trade-off decision between the higher initial cost and lower expected operating costs of an efficient product. A considerable number of studies followed the approach used by Hausman (1979) and used discrete choice models to estimate the discount rates implicit in various purchases of energy-using durables to determine whether households undervalue operating costs when making these trade-offs. Train (1985) and DEFRA (2010) provide extensive reviews of this literature on discount rates in consumers' purchases of energy-using durables. Table 1 summarizes their collection of implicit discount rate estimates by product category.

Table 1 shows that there is a wide range of observed discount rates, differing significantly both between and within product categories. The observed discount rates are for the most part considerably higher than risk-adjusted market interest rates, suggesting the existence of a discounting gap. Howarth (2004) for example assumes that investments in energy efficiency have risk characteristics similar to those associated with typical private sector investments and thus favors the use of a 6% discount rate.[3] Subtracting 6% from the estimates of implicit discount rates presented in Table 1 clearly leaves a positive residual – a discounting gap – in many cases. The discounting gap seems to be particularly large for refrigerators with discount rates in the range of 39% to 300%, a range

[3]Similarly to the current situation, market interest rates in the US were also very low in 2003/2004 (Federal Reserve, 2016).

that can hardly be attributed to larger risk inherent in purchases of refrigerators as opposed to the other product categories.

The larger discount rates for refrigerators could partly be explained by the magnitude effect, as cost savings for efficient refrigerators compared to inefficient appliances are relatively small compared to high cost products as e.g. heating systems or cars (DEFRA, 2010). However, this explanation does not seem sufficient, as for example the discount rates estimated for water heaters, another high cost product, are also very high. In addition, the large variations of discount rate estimates within product categories suggest that some estimates might not be very reliable and are highly dependent on the method and context of elicitation.

The literature mentions different factors that potentially explain the empirical estimates of high discount rates, i.e. the observation of a discounting gap, in households' purchases of energy-using durables. For the subsequent reasoning of this article, I divide these factors into three different categories: Objective factors determining the setting of the purchase decision, subjective factors representing the households' particular decision processes, and variables confounding the empirical estimates of implicit discount rates because they are not considered in the choice model. Figure 1 presents these three categories of factors and lists particular effects from each category as mentioned in the literature.

Figure 1 introduces an additional division of the factors explaining a discounting gap: the "irrational" factors on the left-hand side and the "rational" factors on the right-hand side. These two categories and their importance in explaining a discounting gap and an energy efficiency gap, respectively, are elaborated on in the following two sections.

3 Explaining the Discounting Gap – "Irrational" Factors

The irrational factors potentially cause households to make purchase decisions whose outcome is not in their best self-interest, i.e. it does not maximize their experienced utility. The economically sub-optimal outcome could arise from objective factors determining the setting of the purchase decision as well as from the particular behavioral decision-making in the purchase of energy-using durables. If these factors cause households to purchase durables with lower energy efficiency than economically optimal, empirical estimates of implicit discount rates will produce a positive discounting gap, in this case equivalent to an energy efficiency gap. If these were the lone factors responsible for

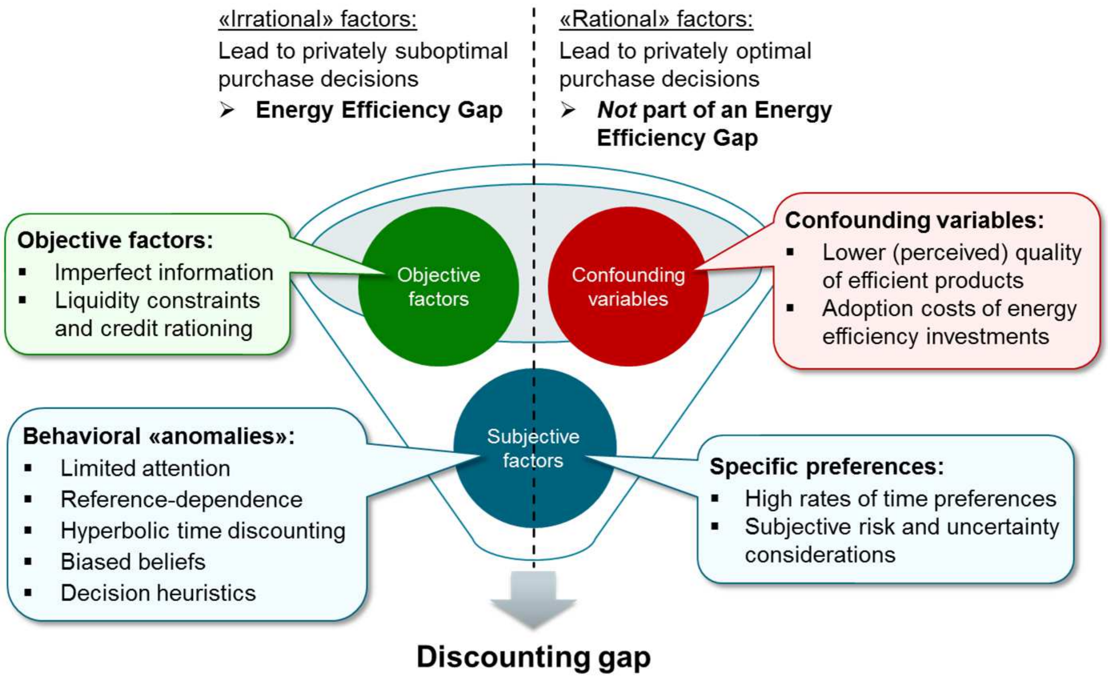

Figure 1: Factors explaining a discounting gap. Objective factors and behavioral anomalies can cause privately non-optimal purchase decisions, i.e. an energy efficiency gap (left-hand side), while specific preferences and confounding variables could explain the existing estimates of a discounting gap without indicating non-optimal purchases by households (right-hand side).

the estimation of a discounting gap, the observation of a discounting gap would portray one-to-one evidence of an energy efficiency gap and call for policy measures trying to minimize this gap. In this section, I review the current state of the literature on these factors in the context of purchases of energy-using durables.

3.1 Objective Factors

Objective factors are exogenous determinants of the setting of the purchase decision which can prevent households from making privately optimal decisions. In economics, market failures are a prime example for objective factors leading to restrictions or distortions of the choice set.[4] I elabo-

[4]Market failures are given when the incentive structure in a given market does not encourage an economically optimal allocation of resources.

rate on the market failures mentioned in the literature to be relevant in the context of households purchasing energy-using durables: Imperfect information and liquidity constraints and credit rationing. If these factors keep households from reaching their optimal level of energy efficiency in the purchase of energy-using durables, then they explain a discounting gap as well as an energy efficiency gap. For a broader depiction of market failures in the energy efficiency context, see Convery (2011), Brown (2004), Jaffe et al. (2004), or Levine (1995). Brown (2004) for example also mention misplaced incentives as a source of market failure, with the landlord-tenant problem as the most popular example. Since these problems occur when an "intermediary" has the authority to act on behalf of a consumer, they are of no help to explain the discounting gap in households' private purchase decisions.

3.1.1 Imperfect Information

Information about the energy efficiency of products is often incomplete, unavailable and difficult or costly to obtain (Brown, 2004). Since energy efficiency is not visible, it is often difficult for the consumer to obtain information about energy efficiency prior to purchasing a product. Additionally, it is also tedious to verify the performance of the product after the purchase since energy efficiency is not readily observable. If consumers are imperfectly informed about energy efficiency characteristics and the potential energy cost savings provided by efficient equipment, energy efficiency investment will be inefficiently low.

Brown (2004) uses the example of the vehicle market where fuel economy is bundled with many other attributes and the consumer is unable to compare two otherwise identical offers solely on the base of different energy efficiency characteristics. In fact, fuel economy is mechanically correlated with weight and horsepower and, in consequence, even highly negatively correlated with price (Allcott and Wozny, 2014). Hence, imperfect information is likely to particularly affect purchases of products with a large number of attributes in various forms, such as cars or televisions.

There are only few studies trying to disentangle the effects of information provision from other explanations of consumer behavior. In an artefactual, computer-based field experiment, Allcott and Taubinsky (2015) assess the effect of an information treatment (they provide information on differences in lifetime and total electricity costs) on the purchase of efficient compact fluorescent light bulbs as opposed to inefficient incandescent light bulbs. While they find a positive effect of the information intervention on the purchase of the energy-efficient compact fluorescent light bulbs, both of their experiments show that large shares of consumers still prefer incandescent light bulbs even after being powerfully informed. Similarly, Min et al. (2014) find that providing estimated annual cost information of light bulbs to consumers led to a significant reduction in their implicit discount rates, but they were still around 100%. These results can either be explained by highly irrational decision-making, or by accepting that other factors besides total costs enter the objective function of households, which is addressed in section 4.2 of this article.

Other studies focus on the effect of information provision provided by energy labels, which are a popular instrument for government and private labeling programs to fill a potential information gap. Newell and Siikamäki (2014) assess the relative importance of various elements of information labels in a stated choice experiment. They find that providing simple information on the economic value of saving energy was most effective in guiding households towards more cost-efficient investments in energy efficiency. Stadelmann and Schubert (2017) show that presenting an energy label guides households towards purchasing efficient appliances, with the most effective information format differing between product categories. In particular, monetary and lifetime information is promising for classes of goods with high absolute electricity costs, such as tumble dryers and freezers, but not so much for classes of goods with low absolute electricity costs like vacuum cleaners (Stadelmann and Schubert, 2017). Concerning the welfare effects of the Energy Star certification program, Houde (2014) finds that consumers rely heavily on the certification, indicating that the label indeed provides new information that influences consumers' purchase decisions. He even ascertains that some consumers over-rely on the presence of the binary Energy Star label and instead neglect other important information like actual energy savings. With respect to the fuel economy label, Camilleri and Larrick (2014) find that preference for fuel-efficient vehicles is highest when fuel-efficiency information is communicated in terms of cost over an expanded, lifetime scale. Ungemach et al. (in press) extend this result with their finding that translated attributes, i.e. expressions highlighting a different aspect of the same attribute (e.g. car fuel economy can be expressed as fuel consumption in miles, fuel cost in dollars, or tons of greenhouse gases emitted), can serve as decision "signposts" because they (1) activate otherwise dormant objectives, such as pro-environmental values and goals, and (2) direct the person towards the option that best achieves the activated objective.

Other studies on the impact of energy efficiency labels show mixed results (see Rohling and Schubert, 2013 and Wiel and McMahon, 2005 for overviews of the literature on energy efficiency labels). While some studies indicate that energy efficiency labels might have a positive impact to reduce imperfect information, other studies found no significant effect. This might partly be due to the fact that even when labels are available, it can still be costly to acquire information, both because labels are incomplete and sometimes biased (Sallee, 2014). Energy labels can be expected to be most useful to reduce the uncertainty about an appliance's energy use for product categories with little heterogeneity in usage patterns, such as refrigerators and freezers. They need to be designed very carefully in order to reduce the effect of imperfect information and maximize the amount of information conveyed at minimum effort cost for households, which is important for policy purposes. If the costs to acquire and process information are too high, which applies more to products with large heterogeneity in usage patterns (e.g. televisions, washing machines, etc.) or little information at the point of purchase (e.g. windows, doors, etc.) it might be rational for the household to be inattentive to energy efficiency in the purchase decision (see e.g. Gabaix, 2014 and Sallee, 2014 for models of rational inattention and costly thinking).

In sum, the existing empirical studies testing the effect of information provision on households' purchases of energy-using durables provide evidence for a small to modest effect of information provision when delivered in the proper metric and scale, but other factors seem to restrain purchases of efficient durables as well.

3.1.2 Liquidity constraints and credit rationing

Purchases of an efficient durable instead of an inefficient product usually evoke higher upfront costs and lower future energy costs. If the difference in upfront costs is large (i.e. for high cost products such as cars, heating systems, etc.), liquidity constraints and credit rationing could prevent some households from purchasing the efficient product (Golove and Eto, 1996). Even if households intended to minimize total costs in their purchase decision as in Equation (1), the financial means needed for the purchase of the optimal appliance could be prohibitively high, leading to the purchase of a cheaper, inefficient product. Liquidity constraints and credit rationing are thus typical examples of a market failure which can lead to an energy efficiency gap by hindering some consumers from making privately optimal purchase decisions for high cost products. In estimates of implicit discount rates, the lack of purchases of efficient products because of liquidity constraints makes it seem as if future energy savings were extensively discounted, leading to the observation of a discounting gap. In a lab experiment, Epper et al. (2011) find that liquidity constraints are an important factor affecting households' general discounting behavior. They estimate that discount rates for liquidityconstrained consumers in a temporal financial trade-off are a staggering 40% higher than for unconstrained individuals, thus explaining part of the extent of estimated discount rates. However, I am not aware of any empirical evidence of the influence of liquidity constraints on estimated discount rates in the purchase of energy-using durables.

Limited access to credit may be caused by asymmetric information on credit risk, which impedes the distinction of borrowers with good credit risk from those with bad credit risk (Gillingham and Palmer, 2014). It will be particularly difficult for low-income consumers with large credit risk to borrow funds. At the limit, a credit-constrained household faces an essentially infinite discount rate for investments in energy efficiency (Brown, 2004). Allcott and Greenstone (2012) state that while credit constraints are a frequently discussed issue in theory, there is not much empirical evidence in the context of energy efficiency.

From a policy perspective, the influence of liquidity constraints could be mitigated with financial incentives, particularly with loan subsidies, which seem to have a larger impact than rebates (Wilson and Dowlatabadi, 2007). A more general point raised by Gillingham et al. (2009) is that if liquidity constraints are an issue for energy efficiency investments, then they will also constrain other types of profitable investments, and any potential solution would have to reach well beyond energy efficiency policy.

The importance of liquidity constraints in purchases of energy-using durables will always be confined to the subgroup of households with severe liquidity constraints. For purchases of many types of energy-using durables, this subgroup is rather small in industrial countries, given the relatively small difference in purchase price between efficient and inefficient products (e.g. light bulbs, air conditioners, refrigerators, etc.). Heating systems could represent an important exception with respect to the price difference between efficient and inefficient appliances, which makes them a promising category for future research on the relevance of liquidity constraints for an energy efficiency gap.

3.2 Behavioral "anomalies"

Households have been observed to systematically deviate from utility-maximization theory in their decision-making, especially when information and choice sets are complex (Wilson and Dowlatabadi, 2007). The different types of deviations from rational choice have been compiled under the term behavioral "anomalies" (see e.g. Thaler, 1989, 1988, 1987). Behavioral "anomalies" can lead households to decisions that are objectively not optimal in their outcome, i.e. they lead to differences between decision utility and experienced utility (Kahneman et al., 1997). If behavioral "anomalies" consistently lead households to purchase durables with lower energy efficiency than optimal, such behavior would explain the observation of a discounting gap corresponding to an energy efficiency gap. Hence, behavioral "anomalies" are located in the left half of Figure 1, which is consistent with the recent literature widely citing these factors as a potential explanation for the existence of an energy efficiency gap (see e.g. Gillingham and Palmer, 2014; Baddeley, 2011; Greene, 2011; Helfand and Wolverton, 2011; Gillingham et al., 2009; Shogren and Taylor, 2008).

3.2.1 Limited attention

In order to simplify complex decisions, consumers process only a subset of the available information and systematically underweight certain information. Gabaix and Laibson (2006) analyze pricing with boundedly rational consumers who do not pay attention to hidden features of product prices. There is a wide range of empirical findings confirming that consumers are inattentive to ancillary product costs that are less salient or obvious such as shipping and handling charges (Hossain and Morgan, 2006), sales taxes (Chetty et al., 2009), or out-of-pocket insurance costs (Abaluck and Gruber, 2011).

In the context of energy-using durables, the "shrouded" price attribute is the running energy cost while the initial purchase price is much more salient. Actual energy use is not observable since the (monthly or yearly) electricity bills generally provide no breakdown of individual end-uses. As a result, households tend to base their purchase decisions for energy-using durables less on energy efficiency and more on other, more visible aspects of the product, such as the initial purchase price (O'Malley et al., 2003). When buying energy-using durables, households might thus be more attentive to the purchase price than to the running energy costs, leading to a higher weight of the former in purchase decisions. The inattention to energy costs is especially pronounced if they are less salient (e.g. for constantly running appliances such as refrigerators or wireless routers) or if they are small compared to the purchase price, as for example for refrigerators or washing machines (Hossain and Morgan, 2006). Due to inattention, households are less likely to purchase an efficient product, which commonly entails a higher purchase price and lower running energy costs than an inefficient alternative. This effect has been widely suggested in the theoretical literature as an important driver of an energy efficiency gap (see e.g. Jaffe and Stavins, 1994; Sanstad and

Howarth, 1994; Anderson and Claxton, 1982; Blumstein et al., 1980).

Empirically, it is very difficult to distinguish inattention from incomplete information. One possibility is to study inattention to energy efficiency with experimental manipulations of salience. In a field experiment on light bulb choice, Allcott and Taubinsky (2015) try to disentangle how much the energy cost information treatment affected choices through increased attention versus updated beliefs. They suggest that both factors contribute to the treatment effect, maintaining that limited attention is a relevant factor in keeping households from buying compact fluorescent light bulbs. Stadelmann and Schubert (2017) find that the presence of a monetary energy label did not drastically improve knowledge of the appliance's energy costs, hinting the identified impact of the energy label might have been mainly driven by increased attention. Complementary use of experimental and non-experimental techniques in future research would help to isolate the effect of increasing salience of energy costs on purchase decisions of energy-using durables.

Concerning energy policy, it is usually recommended to address the cause of the inefficient outcome as directly as possible (Allcott and Greenstone, 2012). However, it does not seem realistic that households' limited attention can be eliminated entirely by policy measures such as energy labels or other instruments of information provision. If households are accepted to partially be inattentive to energy consumption, recent research has shown that the optimal policy is a combination of energy tax, subsidies for high-efficiency products, and energy efficiency standards (Allcott et al., 2014; Tsvetanov and Segerson, 2014, 2013).

3.2.2 Reference-dependent preferences

Markowitz (1952) was the first to suggest that people hold reference-dependent preferences, a notion adopted by Kahneman and Tversky (1979) in their famous paper on prospect theory. Prospect theory accounts for several departures from expected utility theory by claiming that people evaluate outcomes based on *changes* with respect to a reference point and not with respect to the final overall wealth. As an additional deviation from expected utility theory, the utility function in prospect theory is steeper in the loss domain than in the gain domain. This means that a loss with respect to the reference point results in a larger decline in utility than a gain of equal size increases utility – an effect called "loss aversion" (Kahneman et al., 1991). This model of reference-dependent preferences with loss aversion has since been used by many economists and has found empirical support (see DellaVigna, 2009 for an overview).

Concerning the issue of energy-using durables, Greene (2011) asserts that loss aversion could be a factor hindering household investment in energy efficiency and thus causing part of an energy efficiency gap. Since there is some uncertainty with respect to future energy cost differences between an efficient and an inefficient durable, e.g. because of the way the product is used or because of future changes in energy prices, there is a chance that the choice of an efficient product proves not to be profitable in hindsight. The mere possibility of such a loss from the purchase decision could prevent loss averse households from purchasing an efficient product (Greene, 2011). For example, Greene et al. (2009) find that the typical consumer would decline an increase in passenger car fuel economy from 28 to 35 MPG since the expected value of the investment is negative for the typical loss-averse consumer. Reference-dependent preferences with loss aversion can therefore lead to choices that fail to maximize experienced utility: The fear of the small probability of a (utility) loss with respect to the reference point hinders households from making investments with a large probability of a (utility) gain. Another issue is raised by Turrentine and Kurani (2007), who find that when consumers buy a vehicle, they do not have the basic building blocks of knowledge assumed by the model of economically rational decision-making, and they make large errors estimating gasoline costs and savings over time.

I am not aware of any other studies with other product categories empirically examining the impact of loss aversion on purchases of efficient durables. In general, this issue can be expected to compound with increasing product lifetime and hence be relevant for heating systems and water heaters. For appliances running on electricity instead of fuel, I would expect this factor to be less of an issue, as electricity prices are less volatile than fuel prices, which reduces the probability that the purchase of an efficient product proves not to be profitable in hindsight. On the other hand, households might not be aware of the lower volatility of electricity prices or be (even) less knowledgeable with respect to the energy consumption of other product categories, which could increase the uncertainty with respect to future energy cost savings of an efficient product and make it less attractive for a loss averse household.

From a policy perspective, financial incentives for the purchase of efficient products could further reduce the probability of a loss with respect to the reference point in order to lower the barrier for loss averse households to purchase an efficient appliance. Other measures could be targeted at reducing the uncertainty with respect to future energy cost savings, e.g. by insuring households making an investment in energy efficiency against any potential losses, as suggested by Mills (2003).

3.2.3 Hyperbolic time discounting

A robust finding in the experimental literature on risk taking is the fact that people behave as if they distort objectively given probabilities in a systematic way: Broadly speaking, they tend to overweight small probabilities and extreme outcomes and underweight large probabilities and intermediate outcomes (see Fehr-Duda and Epper, 2012, for an overview on probability weighting). Epper and Fehr-Duda (2015) show that people prone to such non-linear probability weighting exhibit hyperbolic discount rates, i.e. declining discount rates over time. Another possible explanation for hyperbolic time discounting is provided by models of reduced self-control and temptation, stating that households are tempted to maximize current utility and incur disutility (i.e. self-control costs) if they resist temptation (see e.g. Tsvetanov and Segerson, 2013 and Gul and Pesendorfer, 2001).

The declining of discount rates over time often leads to time inconsistent choices because households have different preference orderings at different points in time, which violates the axioms of expected utility theory (Frederick et al., 2002; Laibson, 1997; Loewenstein and Prelec, 1992).[5] Time inconsistent choices fail to maximize experienced utility and can thus potentially explain part of an energy efficiency gap (Kahneman and Sugden, 2005).

With respect to the purchase of energy-using durables, hyperbolic time discounting implies that the difference in purchase price (immediate costs) between efficient and inefficient products carries more weight than the difference in future energy costs (delayed benefits), which decreases the attractiveness of the efficient product, particularly for product categories with long (expected) product lifetimes. I am not aware of any empirical studies particularly focusing on hyperbolic discounting in the purchase of energy-using durables. This could be explained by the character of most energy-using durables, which are generally not assumed to be high on a temptation scale and are purchased rather infrequently. Furthermore, some recent studies find little evidence of non-exponential discounting behavior, highlighting a more general need for further research of households' discounting behavior (Andersen et al., 2014; Andreoni and Sprenger, 2012).

[5] Halevy (2015) inspects time inconsistent behavior in more detail. He distinguishes time consistency from stationarity and time invariance and finds that present-biased preferences are not necessarily the main source of time inconsistent choices.

3.2.4 Biased beliefs

If households underestimate the potential cost savings of energy efficiency investments, they might be unwilling to undertake them. However, empirical evidence does not imply a systematic underestimation of potential cost savings. Attari et al. (2014) find that in fact, consumers tend to underestimate energy use of large appliances, but overestimate the energy use of smaller ones. In a survey of households who just purchased a new household appliance, Stadelmann and Schubert (2017) find that households generally overestimate the electricity costs and thus also the potential cost savings of purchasing an efficient appliance, particularly for vacuum cleaners, which are characterized by low absolute electricity costs. Hence, the underestimation of energy use seems to be at most an issue for large products with high energy consumption, if anything.

In an attempt to measure whether systematically biased beliefs contribute to an undervaluation of fuel economy, Allcott (2011) uses survey data to elicit consumer beliefs about future fuel savings from a higher fuel economy vehicle. He finds that consumers suffer from "MPG illusion" – they underestimate the energy cost differences among low-MPG vehicles and overestimate the cost differences among high-MPG vehicles. In a simulation eliminating this bias, Allcott (2013) ascertains that consumers would shift away from both high-MPG hybrids and low-MPG trucks and purchase more medium MPG vehicles. The aggregate effect of MPG illusion on the average MPG of vehicles sold remains ambiguous and does not explain a low demand for efficient products (Allcott, 2011).

Kahneman et al. (1982) provide an extensive list of ways in which judgment diverges from rationality. One example that could be relevant in the context of purchasing energy-using durables is the "law of small numbers", which purports that people make inferences about general probabilities from small sample sizes. The law of small numbers could give way to a discounting gap by biasing households' beliefs about the durability of products. If households assume a shorter lifetime than objectively accurate, the discount rates estimated in the decision model with objective lifetimes will be inflated and present a discounting gap corresponding to an energy efficiency gap. A single bad experience with the durability of a product could – according to the law of small numbers – induce households to generally belief that the lifetime of products is shorter than it veritably is.[6]

[6]Only an underestimation of product lifetime could be a cause of a discounting gap, which is why I use the example of a single bad experience. In principle, bad experiences and good experiences with product durability could cancel out in mean estimates of discount rates. However, Baumeister et al. (2001) show that bad events have greater power than good ones, which means that the effect of bad experiences with product durability can be expected to

This effect can be extended to the general risk perception of households: A biased perception of risk associated with the purchase of energy-using durables of different energy efficiency impacts the estimated discount rates, but there is no empirical evidence that such a tendency adversely affects efficient products.

I am not aware of any other empirical studies of the influence biased beliefs on the purchase of energy-using durables. The existing evidence, while rather sparse, suggests that biased beliefs are unlikely to be a significant driver of an energy efficiency gap. Hence, this factor does not merit priority for energy policy.

3.2.5 Decision heuristics

When facing complex decision problems with many options, abundance of information, or complex information, consumers have been found to use heuristics or so-called rules of thumb to simplify the decision-making process. Decisions heuristics are thus difficult to separate from the above mentioned effects of imperfect information and limited attention, since by definition, applying a heuristic means to be inattentive to part of the information in the decision-making process. DellaVigna (2009) lists the following examples, among others, where evidence in psychology suggests that individuals use simplifying heuristics (p.353):

- *Preference for the familiar* – choosing the option that is more familiar as can be seen for example in brand loyalty or investment in companies investors recognize from their home state (see Huberman, 2001)
- *Preference for the salient* – choosing the option that is most salient as for example the first candidate on a ballot (see Ho and Imai, 2008)
- *Choice avoidance* – avoiding choice altogether, possibly in favor of the default option (see e.g. Iyengar and Lepper, 2000 for the choice of jam taste)

In the context of energy-using durables, applying decision heuristics as the ones mentioned above could lead to a systematic bias of purchase decisions towards inefficient products: They have been around longer and are thus more familiar, they are attractive with respect to the most salient attribute purchase price and they represent the fallback option if choice is avoided altogether.

dominate, which makes an underestimation of lifetime more likely.

The familiarity with energy-efficient products could be influenced by technological progress and the presence of energy labels for different product categories. In the EU for example, additional categories at the top of the energy efficiency scale were first introduced for cooling devices and inefficient appliances at the bottom of the energy efficiency scale were periodically banned, likely leading to higher familiarity with efficient appliances.

Empirically, Lacetera et al. (2012) as well as Turrentine and Kurani (2007) present evidence of decision heuristics used in purchases of cars, but they do not find evidence that the heuristics would systematically favor inefficient cars. With respect to energy labeling, several studies find that households confronted with the EU Energy Label employ decision heuristics, focusing primarily on energy efficiency classes while neglecting more detailed information on energy consumption (see e.g. Stadelmann and Schubert, 2017, Andor et al., 2016, Waechter et al., 2015a, Waechter et al., 2015b). In a hypothetical study, Waechter et al. (2015b) find that because of such decision heuristics, the EU Energy Label might even cause households to chose a higher-consuming, larger product because they ignore the fact that the energy efficiency rating is a grade of energy consumption relative to the size of a product. In a field experiment, Stadelmann and Schubert (2017) partly confirm this finding by showing that energy labels with relative information on energy consumption lead to an increase in mean volume of purchased freezers. These findings illustrate that policy measures such as energy labels need to be designed carefully and consider the decision heuristics used by households in order to prevent inadvertent (side) effects of the measure.

4 Explaining the Discounting Gap – "Rational" Factors

The right-hand side of Figure 1 displays potential factors explaining a discounting gap without portraying privately non-optimal, irrational behavior. Based on their time and risk preferences, households may deliberately use a larger discount rate than the market return on investments with similar risk. Furthermore, the estimates of implicit discount rates using discrete choice models – as presented in section 2 – can be confounded if the choice model does not consider all the relevant decision factors. Due to these factors, a discounting gap can come about despite purely rational, utility-maximizing decision-making by households. A discounting gap based only on rational decisions does not correspond to an energy efficiency gap and hence would not legitimate policy interventions from an economic perspective.

4.1 Specific preferences

Based on their specific preferences, households might deliberately use discount rates that are higher than objectively risk-adjusted market interest rates. While such behavior contributes to the observation of a discounting gap, it maximizes households private utility and is not causing an energy efficiency gap. Naturally, this issue is amplified for product categories with longer (expected) product lifetimes, as the discount rate is applied to a longer time horizon and hence carries more weight.

4.1.1 High rates of time preferences

In economics, time preferences specifically refer to the preference for immediate utility over delayed utility (Frederick et al., 2002). Discounted utility theory assumes that the same rate of time preference applies to all forms of consumption, i.e. time preferences are not context-dependent (Frederick et al., 2002). Based on this assumption, Frederick et al. (2002) particularly distinguish between time preferences and time discounting, which broadly covers any reason for caring less about a future consequence, including uncertainty and changing tastes. This subsection is devoted specifically to individual time preferences.

The most direct and pure form to elicit time preferences is by varying the timing and the size of financial pay offs. Newell and Siikamäki (2015) elicited individual discount rates using a hypothetical choice between a $1'000 payment available in one month and a higher payment available in 12 months. They find substantial heterogeneity in individual discount rates, with a mean rate of 19 percent, a median of 11 percent, and a standard deviation of 23 percent. Using similar methods in a representative nation-wide study in Switzerland, Enzler et al. (2014) find mean discount rates of 27 percent when excluding extreme values. In one of very few incentivized experimental studies, Epper et al. (2011) report subjective discount rates of approximately 30% p.a. In a comparison of experimental methods to measure time preferences, Andreoni et al. (2015) find even larger discount rates up to approximately 100% p.a. All of those recent estimates of discount rates are much higher than risk-adjusted market interest rates.

In terms of purchases of energy-using durables, households' "pure" time preferences rationally influence the discount rate at which they personally discount future financial pay offs. If households value present consumption relatively high compared to future consumption, securing a large level of present consumption maximizes their experienced utility. In the trade-off between an efficient and an inefficient durable, purchasing the inefficient product with the lower purchase price preserves a higher level of present consumption possibilities. Hence, high rates of time preferences favor the purchase of inefficient products and raise the barrier for the purchase of efficient products. If a household prefers some amount of consumption now to the higher amount of consumption in the future as achievable with a return equal to the risk-adjusted market interest rate[7], it uses a higher discount rate than the market for its privately optimal decision.[8] This part of a discounting gap reflects households' pure time preferences and constitutes a rational, private optimization in the purchase of an energy-using durable.

In sum, recent elicitations of time preferences indicate that part of the discounting gap in purchases of energy-using durables can be ascribed to high rates of time preferences inherent in households' intertemporal trade-offs. Decision-making based on high rates of time preferences is rational and thus not part of an energy efficiency gap.

4.1.2 Subjective risk and uncertainty consideration

The outcomes of investments in energy efficiency are uncertain due to various reasons, such as uncertainty about energy prices, uncertainty about the performance and lifetime of a product, or uncertainty about the real-world energy consumption of a product (Greene, 2011). The uncertainty resolves only gradually over a long time period. Therefore, households' risk and uncertainty preferences play an important role in their purchase decisions for energy-using durables. Objective risk of energy efficiency investments does not contribute to a discounting gap, as it is already considered in the risk-adjusted market interest rate deducted from the estimated implicit discount rates. However, it is possible that based on their *subjective* risk preferences, households require a larger risk premium, which would contribute to the observation of a discounting gap.

For households purchasing energy-using durables, it seems realistic to assume uncertainty with respect to both the amount of energy the appliance will use as well as the costs of energy use based

[7]The risk-adjusted market interest rate corresponds to the price financial markets set for the trade-off of present versus future consumption.

[8]I concede that it might not be realistic for rational discount rates to arbitrarily exceed market rates. If this was the case, households with very high rates of time preference should always exhaust their credit limit as long as the borrowing costs are lower than their time preferences and spend all their money immediately – unless risk preferences limit such behavior.

on future energy prices. Most evidence suggests that people are generally ambiguity[9] averse (see e.g. Wakker, 2010; Epstein, 1999; Camerer and Weber, 1992). Ambiguity averse households try to reduce the level of uncertainty they are exposed to. In the context of energy-using durables, ambiguity averse households can be expected to generally purchase appliances of *higher* energy efficiency in order to reduce the uncertainty from future energy costs. Such behavior would lead to estimates of *lower* implicit discount rates and therefore cannot explain either a discounting gap or an energy efficiency gap. Along these lines, I cannot think of any other examples of how subjective risk and uncertainty consideration would increase households' privately rational discount rates, while examples of irrational decision-making in the face of uncertainty have already been discussed in section 3.2.

4.2 Confounding Variables

Besides the explanations presented above, modeling errors in the discrete choice models used to estimate implicit discount rates in purchases of energy-using durables are likely contributing to the observed discounting gap. Specifically, the decision models used by Hausman (1979) and others infer utility of the outcomes from observed choices. They abstract from product attributes that were not observed and from potential implementation barriers for the efficient products. If efficient products have systematically worse unobserved characteristics than inefficient products, they will rationally be purchased less frequently than predicted in a simpler model not accounting for these factors. The omitted variables make it seem as if households strongly discounted future energy cost savings achievable with the purchase of an efficient instead of an inefficient product, inflating estimated discount rates. A misspecification of households' utility functions can thus falsely lead to the interpretation that households use irrationally high discount rates.

4.2.1 Lower (perceived) quality of efficient products

Products of varying energy efficiency levels differ from each other in ways that are often omitted in decision models in the literature. Producers may generate efficiency improvements by trading off other product attributes for enhanced energy efficiency. In that case, purchasing efficient products may entail opportunity costs in the form of lower product quality compared to inefficient products.

[9] Ambiguity means uncertainty with respect to the true underlying probability.

Howarth (2004) provides the example of car manufacturers achieving increased fuel economy by reducing the size and weight of new vehicles, reducing their crashworthiness and thus compromising on vehicle safety. Additionally, Allcott and Greenstone (2012) mention that efficient cars often have fewer luxury amenities than inefficient models. Not controlling for size, safety and households' tastes for luxury amenities in the econometric analysis of car purchases leads to an upward bias in the estimation of implicit discount rates. This effect can lead to estimates of a discounting gap which is not indicative of an energy efficiency gap, as the observed product choice maximizes utility for households.

Light bulbs are another famous example for hidden costs of efficient products. Fluorescent light bulbs produce a different light spectrum than incandescent light bulbs, which some people perceive as "cold" and aesthetically inferior (Howarth, 2004). While both types of light bulbs may objectively provide the same energy service of lighting, the quality of the products is perceived differently by some people, leading to differences in utility. This example illustrates why it is not trivial to solve the problem of differences in perceived quality of products by including various product attributes in analyses of cross-sectional choice data. Observing and accurately measuring all product characteristics is often impractical, and households' valuation of some attributes – as for example the preference for different light spectra – would have to be ascertained in separate economic experiments.

Examples for other product categories with lower perceived quality of efficient products could be if consumers expect the cleaning of energy-efficient dishwashers, washing machines, or vacuum cleaners to be inferior, but I am not aware of any empirical evidence of such perceptions.

One possibility to eliminate the problem of unobserved product attributes is to use differencing of fixed-effects models with panel data. In the purchase of vehicles for example, conditioning on vehicle fixed effects sweeps out all observed and unobserved characteristics and allows to directly test whether relative prices for vehicles with different fuel economy ratings move one-for-one with changes in the present discounted value of fuel costs, which would be expected when all market participants are rational. Prices moving less than one-for-one would be a sign of consumers undervaluing fuel costs, and hence of an energy efficiency gap. In recent studies using this method, Allcott and Wozny (2014) suggest that some investment inefficiencies are present, while Busse et al. (2013) and Sallee et al. (2009) find no evidence of an energy efficiency gap. Allcott and Greenstone (2012) state that even if there are in fact some investment inefficiencies in the automobile market, the welfare losses would be relatively small.

4.2.2 Adoption costs

Another type of opportunity costs associated with energy efficiency investments are adoption costs. Such costs can take many forms, including time spent finding or installing a more energy-efficient product (i.e. search costs) and unobserved implementation costs (Gerarden et al., 2015a). Howarth (2004) again uses light bulbs to provide an example for the latter: Compact fluorescent bulbs tend to be bigger and bulkier than the conventional incandescent light bulbs they replace. Therefore, they do not work well with certain lighting fixtures and are purchased less frequently.

Another example I can think of would be electric cars: While the total lifetime cost of an electric car might be lower than for a car with internal combustion engine, the usage of an electric car can entail significant adoption costs if the infrastructure of electric vehicle charging stations is not sufficient.

Ignoring possible incremental adoption costs of efficient products compared to inefficient products in the discrete choice model leads to inflated estimates of implicit discount rates. Hence, adoption costs represent a confounding variable in many empirical estimates of implicit discount rates, adding to the size of the observed discounting gap. In principle, adoption costs could be incorporated in decision models, but in practice this is often inhibited by data and measurement challenges. Experimental and quasi-experimental research designs offer another possible avenue for quantifying these costs.

5 Conclusion

Since the 1970s, a large body of literature used an econometric approach to estimate the discount rates implicit in actual purchase decisions for energy-using durables. Estimates of discount rates considerably higher than risk-adjusted market interest rates – a discounting gap – have been interpreted as evidence of an energy efficiency gap. In this article I challenge the assumption that high implicit discount rates estimated from observed choices are directly indicative of an energy efficiency gap.

The underlying issue for measuring an energy efficiency gap is to correctly quantify each variable influencing individual decision-making. Conventional estimates as presented in section 2 rarely satisfy this condition, as they measure implicit discount rates without controlling for several confounding variables influencing households' purchase decisions for energy-using durables. The literature particularly mentions the examples of cars and light bulbs to entail confounding variables, but other product categories are likely affected as well. The unobserved components – such as search costs, differences in product attributes, and differences in the valuation of attributes – are part of households' utility functions and are thus rationally considered in a privately optimal decision. While augmenting the estimates of implicit discount rates, these factors do not explain an energy efficiency gap. The same can be said if high rates of time preferences and subjective risk and un-certainty considerations cause households to deliberately discount future monetary flows heavily, which particularly concerns product categories with long product lifetime. Therefore, the prevalent evidence of a discounting gap overstates the size of an energy efficiency gap.

On the other hand, market failures and behavioral anomalies explain a discounting gap as well as an energy efficiency gap. These factors cause some households to purchase an inefficient appliance even if the efficient product would be privately optimal, i.e. maximize their utility. Empirical evidence implies that imperfect information and limited attention are likely part of the problem in causing an energy efficiency gap. These factors particularly affect purchases of products with a large number of attributes in various forms, such as cars or televisions, and purchases of products with low salience of energy consumption or small energy costs compared to the purchase price, such as refrigerators or washing machines. Since much of the existing literature on the impact of these factors is based on hypothetical choice experiments, further empirical research, especially using large-scale evaluations and randomized controlled trials, is desirable to provide more thorough evidence of decision processes in households' purchases of energy-using durables.

Gaining further insight into the causes of an energy efficiency gap is essential for policy purposes in order to design policy measures targeted at mitigating these causes. In the presence of imperfect information and limited attention, information strategies like energy labels could increase the economic efficiency of purchase decisions and households' experienced utilities. However, it does not seem realistic that households' limited attention can be eliminated entirely by policy measures such as energy labels or other instruments of information provision. If households are partially inattentive to energy consumption, the optimal policy complements information instruments with an energy tax, subsidies for high-efficiency products, and energy efficiency standards (Allcott et al., 2014; Tsvetanov and Segerson, 2014, 2013). Closing an eventual energy efficiency gap presents a win-win opportunity: It increases households' private welfare by leading them to economically optimal decisions and it raises societal welfare by reducing the negative externalities inherent in the production and consumption of energy.

Even if there is no energy efficiency gap in the economic definition used in this article, increasing the energy efficiency of energy-using durables could be socially desirable as long as energy consumption causes negative externalities. However, measures to increase energy efficiency levels beyond the economists' narrow optimum cannot appeal to the "win-win" argument, as they might not be privately optimal for all households. Policy measures interfering with deliberate decisions based on households' preferences ought to be legitimated with overall welfare benefits and are only economically desirable if they pass a benefit-cost analysis.

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