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Review

Mind the gap? Critically reviewing the energy efficiency gap with empirical evidence

Marcel Stadelmann

ETH Zurich, Chair of Economics, Institute for Environmental Decisions (IED), Clausiusstrasse 37, 8092 Zurich, Switzerland

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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.

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E-mail address: marcel.stadelmann@econ.gess.ethz.ch

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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 [1] 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. [2], 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:

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

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. 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 [3–8]. 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. [5] estimate that the United States could reduce annual energy consumption by 23% by deploying an array of financially profitable energy efficiency measures, with the residential sector accounting for 35% 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” [9]. 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 Eq. (1) [10]. 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 Eq. (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. [11], 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 [12]. 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 Eq. (1), it is possible to estimate implicit discount rates ϑ by applying revealed preference methods on actual purchase data of energy-using durables [13]. 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. [14] provide a simple stylized example of the method to estimate implicit discount rates (p. 2): Suppose a consumer is indifferent

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

[2] This is in contrast to a recent working paper by Gerarden et al. [15] 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.