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Explaining the energy efficiency gap - Expected Utility Theory versus Cumulative Prospect Theory

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ABSTRACT

Energy efficiency is one of the key factors in mitigating the impact of climate change and preserving non-renewable resources. Although environmental and economic justifications for energy efficiency investments are compelling, there is a gap between the observable and some notion of optimized energy consumption - the so-called energy efficiency gap. Behavioral biases in individual decision making have been resonated by environmental research to explain this gap. To analyze the influence of behavioral biases on decisions upon energy efficiency investments quantitatively, we compare Expected Utility Theory with Cumulative Prospect Theory. On basis of a real-world example, we illustrate how the extent of the gap is influenced by behavioral biases such as loss aversion, probability weighting and framing. Our findings indicate that Cumulative Prospect Theory offers possible explanations for many barriers discussed in literature. For example, the size of the gap rises with increased risk and investment costs. Because behavioral biases are systematic and pervasive, our insights constitute a valuable quantitative basis for environmental policy measures, such as customer-focused and quantitatively backed public awareness campaigns, financial incentives or energy savings insurances. In this vein, this paper may contribute to an accelerated adaption of energy efficiency measures by the broader public.

1. Introduction

One of the key factors in mitigating the impact of climate change and preserving non-renewable resources is energy efficiency (EE). Recent sweeping environmental policy advances aim to drastically increase EE to combat global climate change. In its "Energy Roadmap 2050", the European Commission, by 2050, aims to reduce energy consumption of existing building stock by 80% relative to 2010 levels (European Commission, 2012). Thereby, investments in EE measures for buildings are one of the European Commission's focus as the building stock is responsible for 40% of energy consumption and 36% of CO_2 emissions in the EU (European Commission, 2017). Furthermore, the European Commission has set EE as one of its main objectives ("putting energy efficiency first") and wants to accelerate building renovation rates (European Commission, 2016). Likewise, the U.S. Department of Energy has announced a massive program to promote EE (Department of Energy, 2015). The environmental and economic justifications for investing in EE are compelling. According to Granade et al. (2009), energy consumption in the U.S. could be reduced as much as 23% by 2020 with cost-effective measures. Furthermore, most related theoretical work has stressed the economic cost-effectiveness of corresponding EE measures. However, and despite its widely asserted profitability, there seems to be an EE gap between the observable use of energy and some notion of optimized use (Rosenfeld et al., 1993; Brown et al., 1998). The EE gap, also called the EE paradox, is defined as the phenomenon that, although EE investments "seem to present clear economic and environmental advantages, the level of investment in them does not reach the levels which would correspond to such benefits" (Linares and Labandeira, 2010, p.575–76). The aim of this study is to quantitatively compare the prevailing explanations of the EE gap based on rational decision-makers with explanations based on insights about psychological biases in decision-making.

1.1. Explanations for the EE gap

Most of the explanations of this EE gap are based on standard neoclassical theory. In this vein, market failures, like environmental externalities, or imperfect information are identified as the main barriers to EE investments. From this point of view, decision-makers make rational decisions that maximize individual expected utility. In the context of EE choices, these decisions involve investments optimizing the result of the tradeoff between higher initial investment costs and

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increasing energy savings, depending on uncertain future energy expenses. Given perfect information and correct prices, it is assumed that the decision-maker perfectly and rationally processes information to maximize expected utility. However, the rationality framework is not able to encompass all possible explanations for the EE gap and several researchers have seriously questioned the assumption of a rational decision-maker. In this way, those in behavioral economics propose that individuals are prone to a multitude of systematic biases that affect decisions in pervasive ways (Barberis, 2013). The specifics of EE investments, such as long time horizons and high uncertainty about future savings, contribute to behavioral biases in individual decision-making. Many psychological biases are attributable to EE investments and are cited as good explanations for the EE gap (Greene, 2011). Yet, while recent environmental policy literature often states the importance of behavioral biases, it mainly discusses these issues just qualitatively. For meaningful policy conclusions, however, a quantification of such behavioral effects might offer valuable information regarding the ecological and economic potential of possible measures. One approach to capture such behavioral effects in a quantitative model is the well-known Prospect Theory (PT) of Kahneman and Tversky (1979). To quantitatively analyze the influence of behavioral biases when deciding upon EE investments, we compare a rational Expected Utility Theory (EUT) decision-maker with a PT decision-maker who decides upon perceived value.

1.2. Cumulative Prospect Theory as a quantitative model for explaining the EE gap

Despite the call for the use of quantitative models that are not based on expected utility (non-expected utility models) for environmental policy analysis (Shaw and Woodward, 2008), so far the application of PT to the case of EE investments is virtually absent. To describe the behavior of decision makers, and, in particular, to capture different systematic behavioral biases, PT mainly comprises four elements (Barberis, 2013; Kahneman and Tversky, 1979):

(1) *Reference dependence*: Decision-makers utility is described by reaction to changes in wealth (gains and losses) related to their current reference point (typically the status quo) rather than upon total wealth. Henceforth, outcomes evaluatedrelative to a reference point will be prefixed with a Δ
(2) *Loss aversion*: Decision-makers value the impact of losses bigger than that of gains.
(3) *Diminishing sensitivity*: Decision-makers are risk-averse in the domain of gains but risk seeking in the domain of losses. Thereby, with growing distance from the reference point, the impact of an outcome diminishes.
(4) *Probability weighting*: Decision-makers weight the probabilities of the outcomes instead of using statistical probabilities and underweight average events (center of the distribution), but overweight events with low probabilities (tails of the distribution).

As PT is mainly applicable to individual decision-making, the focus of this paper is on private decisions. Therefore, as a real-world application we analyze a prototypical EE investment in the weatherization of an owner-occupied residential building. This kind of investment bears significant potential for EE through improved insulation of the building envelope, while the costs for achieving the energy savings are relatively low (Jakob, 2006). Nevertheless, the level of investment still seems to fall below the optimal level (Granade et al., 2009). In this context, we apply Cumulative Prospect Theory (CPT), which was introduced by Tversky and Kahneman (1992) as an advancement of the original PT to overcome the possible violation of first-order stochastic dominance. Thereby CPT allows for an explicit quantification of many well recognized behavioral biases and enables a comparison with EUT.

While much research on the EE gap has stressed the importance of behavioral economics, to date empirical and quantitative theoretical work on CPT and its elements in the context of EE investments is scarce. Therefore, the contribution of our paper is threefold: First, to the best of our knowledge, we are the first to implement all elements of CPT to quantitatively evaluate EE investments. In particular, we show how CPT can be applied to analyze EE investment decisions quantitatively based on a Net Present Value (NPV) approach. Second, we analyze if and to what extent, CPT can explain the EE gap, and the main parameters influencing it. Therefore, we use CPT to evaluate the distribution of possible NPVs of an EE investment as compared to EUT in order to deliver first quantitative evidence on the contribution of CPT to explaining the EE gap. Third, as our approach enables a thorough analysis and quantification of behavioral biases, we help to make behavioral biases addressable and correctible by environmental policy measures. Even though, we provide micro-level insights into the decision-making of an individual EE investor, the results from this paper support policy makers in generating incentives that accelerate the adoption of EE technologies on macro-level.

The remainder of this paper is organized as follows. In Section 2, we review research on the EE gap and barriers to investing in EE. Thereby, we put a focus on behavioral barriers. Section 3 includes descriptions of EUT and CPT in order to evaluate EE investments. This is followed by a discussion of specifics of EE investments, and how these are depicted within a NPV approach outlined in Section 4. The simulation analysis and its results are presented and discussed in Section 5. Finally, the conclusions and contributions to literature (and practice) are discussed in Section 6.

2. The energy efficiency gap

In a very general form, Jaffe and Stavins (1994a, p.804) refer to the EE gap as “the paradox of gradual diffusion of apparently cost-effective energy-efficiency technologies”. Brown (2001, p.1198) defines the EE gap as “the difference between the actual level of investment in energy efficiency and the higher level that would be cost-beneficial from the consumer's (i.e., the individual's or firm's) point of view”. Thus, in our context, we define the EE gap as the difference between observable investments in EE and a cost-effective level of EE investments that would be optimal from the perspective of a EUT decision-maker. Estimates for the size of the EE gap are wide ranging, but there is substantial empirical evidence for its existence. There are three streams in literature that indicate the existence of the EE gap based on different approaches: (1) macro-level engineering-economic studies (see e.g., Brown et al., 1998; Granade et al., 2009; Rosenfeld et al., 1993). The basic approach in such studies is to calculate the NPV of possible EE measures given assumed capital costs, energy prices, investment horizons, and discount rates (Allcott and Greenstone, 2012). (2) Case studies for specific products and technologies, which show that consumers and firms often choose not to invest in highly cost-effective EE measures (DeCanio and Watkins, 1998; Gates, 1983; Koomey and Sanstad, 1994; Koomey et al., 1996; Meier and Whittier, 1983). And (3) a large part of the evidence on the EE gap is based on analyses of implicit discount rates. Numerous studies report the observation that consumers use high implicit discount rates in making EE investment decisions (Dubin and McFadden, 1984; Gately, 1980; Hausman, 1979; Min et al., 2014; Ruderman et al., 1987). However, sometimes the existence of the EE gap is viewed skeptically. For example, Allcott and Greenstone (2012) state that the EE gap is possibly only in the range of about 1–2% of energy use. Nevertheless, the majority of authors indicate that energy markets are full of barriers that could explain the EE gap.

2.1. Barriers to EE investments

Generally, barriers to EE investments represent factors that limit the diffusion of cost-effective EE measures (Vine et al., 2003). There are