Decision making in energy efficiency investments – a review of discount rates and their implications for policy making

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Abstract
I look at the inter-temporal decision making of economic actors with a special focus on energy efficiency investments using a discounted-utility model. I review literature to derive empirical discount rates for individuals as well as companies, and look at underlying factors influencing their investment behaviour such as socio-economic factors. The reported discount rates for individuals vary considerably within the population with an average discount rate of 43 % and median of 21 %, which is considerably above the weighted average cost of capital or the interest rate on government bonds. This discrepancy can best be explained by the 'bounded rationality' of individuals. There appears to be no significant difference in an individual's assessment of energy efficiency investments compared to other types of investments. For legal entities, the available data is more limited but points to a similarly high average discount rate of 46 %, which is seen as a result of the interplay of boundedly rational actors with simplistic financial evaluation methods. These are insufficient to evaluate appropriately the financial viability of energy efficiency investments.

The discount rates observed in the population are then compared to the required discount rates for investments in energy efficient products. Only around half of all profitable investments are undertaken, being an indicator for the size of the economic 'energy efficiency gap'. In a next step, the impact of public policy on investment decisions is assessed. I review literature on the effect of energy efficiency policies, counteracting the 'bounded rationality' and often reducing average discount rates by around 30 % through improved information or successful risk mitigation. I conclude with a summary of main factors influencing an economic actor's decision making, followed by recommendations on how to design public policies to maximise their effect.

Introduction
Inter-temporal choices are at the core of any investment decision since such decisions involve trade-offs among costs and benefits occurring at different times. Investments in energy efficiency are no exception; investors need to weigh higher upfront costs against future energy savings. Understanding the inter-temporal decision making process is at the attention of much economical and psychological research, and a prerequisite for effective policy making.

Standard neoclassical economic theory postulates that economic actors behave perfectly rationally. They maximize their self-interest, and that self-interest has broadly defined consistency properties across different decisions (McFadden, 2001). In reality, economic actors are limited by the information they have, the cognitive limitations of people's minds and the finite amount of time they have to make a decision. Simon (1957) recognised these constraints in the concept of 'bounded rationality' as a more realistic, alternative basis for the description of economic behaviour. Today, growing evidence shows that cognitive constraints may influence investment decisions, and such constraints, ranging from self-control problems to reference dependent preferences to biased beliefs and inattention, are behind the actual behaviour of people (Frederick et al., 2002; Gillingham & Palmer, 2014). The reason is that not economic logic and optimising analyses but heuristic rules with imprecise routines and rules of thumb are the proximate drivers of most human behaviour (McFadden, 2001; Sorrell et al., 2010). Even for economic actors with sufficient resources for in-depth investment assessments, such as large companies, 'rules-of-thumb' appear to be common and a result of underlying constraints (Jackson, 2010).

Bounded rationality is often cited as one of the reasons for the 'energy efficiency gap' (DEFRA, 2010; Gillingham & Palmer, 2014; Schleich, 2007; Sunstein & Reisch, 2014): the difference in the energy efficiency investment that would result from economically optimal inter-temporal choices and the investment that results from actual decision making behaviour of economic actors. Especially the failure to make energy saving investments that have positive net present value has been the subject of much economics literature (Gillingham & Palmer, 2014), and suggests that when selecting the energy efficiency of a purchased durable good, economic actors behave as if they heavily discount future energy savings (Qiu et al., 2015; Train, 1985). This behaviour leads to a slower diffusion of energy-efficient products than would be expected if economic actors made all positive net present value investments, which has a triple-down effect on the investments of others, because a faster diffusion of new technologies correlates negatively with the technologies' retail prices, making energy efficient investments more attractive.

While some literature argues in principle against the actual existence of such a gap (Sutherland, 2003), only a thorough understanding of economic actors' inter-temporal choices allows for an analysis of the existence and potential size of an energy efficiency gap. Central to this understanding is knowledge about the relative weighting of future benefits in inter-temporal decision making: how do economic actors value future utility compared to today's utility? Paul Samuelson was the first to formalise this comparison into the discounted-utility (DU) model in 1937, which is widely accepted as a descriptively accurate representation of actual behaviour and used as the normative standard for cost-benefit analyses in public policy (European Commission, 2008; Frederick et al., 2002). A central assumption of the DU model is that all of the disparate motives underlying inter-temporal decision making can be condensed into a single parameter: the 'discount rate'.

Most literature on the economics of inter-temporal decision making uses the discount rate to describe economic actors' behaviour. The aim of this paper is to present the variety of discount rates reported according to the type of economic actor (people as well as firms) and allow for conclusions on policy making to reduce the negative economic effects of bounded rationality.

After presenting the DU model in detail, this paper gives an overview of the extreme diversity of discount rates reported in literature for natural persons, including their distribution in the population, as well as a more limited overview for firms. Following a presentation of discount rates necessary for investments in energy efficiency and the impact of energy efficiency policies on these, I close with remarks on the design and assessment of energy efficiency policies, such as for economic modelling, because the use of discount rates in energy system modelling (Hermelink & de Jager, 2015) and their implications for policy aims in the frame of the EU's 2030 targets (Steinbach & Staniaszek, 2015) has received an increasing attention of stakeholder's in the policy making process.

Modelling Inter-Temporal Choices

Inter-temporal decision making can best be described within a mathematical framework. The DU model describes an economic actor's inter-temporal choices by a utility function U^t over the possible time-dependent consumption profiles $(c_t,\ldots,c_T)$ in a specific functional form:

$$U^t(c_t, \ldots, c_T) = \sum_{k=0}^{T-t} D(r,k)\, u(c_{t+k}) \qquad (1)$$

In this form, $u(c_{t+k})$ expresses the economic actor's instantaneous utility function – the actor's well-being in period t+k. The economic actor's relative weighting D(r,k) is attached at the time t to the actor's well-being in period t+k, and depends on the discount function at the rate of time preference r.

While in at least some situations the assumptions underlying the DU model have been tested and found to be descriptively invalid, the popularity of this model can be explained largely by its simplicity and its resemblance to the familiar compound interest formula rather than as a result of empirical research demonstrating its validity (Frederick et al., 2002). In fact, the economic actor's relative weight D(r,k) is usually simplified to represent compound interest weighting with a constant discount rate r at the time t of the evaluation:

$$D(r,k) = \left(\frac{1}{1+r}\right)^k \qquad (2)$$

But constant discounting entails an equity in the way a person evaluates time: delaying or accelerating two dated outcomes by a common amount should not change preferences between the outcomes (Frederick et al., 2002). Only the assumption of constant discounting permits a person's time preference to be summarised as a single discount rate. If constant discounting does not hold, then characterising an economic actor's inter-temporal choice requires the specification of an entire discount function.

Representing the economic actor's instantaneous utility function in monetary terms, the DU model is equivalent to the net present value (NPV) formula used in financial analysis:

$$NPV(r,T) = \sum_{k=0}^{T} \left(\frac{1}{1+r}\right)^k u_k \qquad (3)$$

The resemblance of the DU model to the NPV appears to further facilitate the DU model's mathematical expression identical to the NPV. As a result, the DU model describing an economic actor's behaviour and the NPV calculation assessing the financial impact of a choice often get mixed and confused. While the NPV is commonly used in the financial analysis of investment decisions of economic actors (especially companies), the DU model in the NPV representation is a description of an economic actor's inter-temporal decision making. In other words, not every economic actor uses the NPV in inter-temporal decision making, but every inter-temporal decision made by economic actors can be described in the DU model.

It follows directly that the discount rate applied by the economic actor in the financial NPV assessment might be different than the behavioural discount rate the economic actor possesses in the DU model; for example, a company might discount future cash flows with their weighted average cost of capital

(WACC) and then take a decision based on the payback period of the investment, which is smaller than the investments' lifetime. In such a case the behavioural discount rate in the DU model is, by definition, higher than the WACC.

In general, the reasons for non-market behavioural discount rates can be classified into six different categories (Sorrell et al., 2010): risk, imperfect information, hidden costs, access to capital, split incentives and bounded rationality. Economic models using only one single formulation to predict inter-temporal choices, therefore assuming the same behavioural and financial discount rate, implicitly assume that the economic actor is perfectly rational and the discount rate observed resembles the correct costs of capital. This is a strong assumption with serious consequences if violated: economic modelling will systematically underestimate the financial benefits of energy efficiency investments or overestimate an economic actor's willingness to invest in energy efficiency.

Furthermore, this assumption also implies that an energy efficiency gap cannot exist (neglecting externalities) – an economic actor's choice is automatically the economically optimal decision as represented in the NPV calculation. Acknowledging externalities, the use of fossil fuels shows a further problem: the production and consumption of energy generate major environmental and health externalities as well as uncertainties from the security of supply, which are usually not fully factored into market prices. Hence, even if economic actors apply discount rates equal to market interest rates, their behaviour can be economically inefficient (Cohen et al., 2015).

Inter-Temporal Decision Making of Individuals

Since the end of the 1960's, there have been many attempts to measure the discount rate of individuals (Frederick et al., 2002; Train, 1985). Some of these estimates are derived from observations of actual behaviours (e.g. the choice between electrical appliances that differ in their initial purchase price and long-run operating costs). Others are derived from experimental elicitation procedures (e.g. respondents' answers to the question "Which would you prefer: €100 today or €150 one year from today?"). This paper tries to cover as many of these attempts as possible. In total, 72 sources were used to derive 204 unique discount rates, many of them with an additional maximum and minimum value presenting the possible variation across the underlying sample.

The lowest discount rate reported is -2.1 % for investment decisions on new air conditioners (Min et al., 2014), reflecting that some economic actors make investments that do not pay off financially, and the highest is 96,000 % for delay decisions of heroin consumers (Ainslie & Haendel, 1983). Other studies looking at drug addictions or health come to similarly high results: for example 27,875 % (Kirby et al., 1999), 5,400 % (Madden et al., 1997) or 9,507 % (Chapman et al., 1999). Taking into account all these extreme rates the calculation of the average[1] discount rate across all studies yields 738.8 %.

While these examples are illustrating the effect of a drug addiction in inter-temporal choices well, their relevance for a study on investment decisions in energy efficiency is arguably small. Therefore, seven abnormally high discount rates above 1,000 % are omitted in the further analysis, bringing the number of unique discount rates used in this analysis to 197.

Excluding these outliners yields an average discount rate of 43 % and a median discount rate of 22 % (11 % first quartile and 41 % third quartile). Figure 1 gives an overview of the distribution of all discount rates over the time they were made public. In contrast to the previous notion of an increase in the value of reported discount rates over time (Frederick et al., 2002), no such trend can be seen in this data set. An explanation could be the much smaller data basis of previous studies and the inclusion of more recent findings in this analysis.

Overall, the height of the reported discount rates presented in Figure 1 is striking. The average and median discount rate are far above the WACC usually observed on capital markets. This raises the question if the reviewed studies have inherent methodological issues, which would lead to a constant overestimation of the discount rate. A well known example of such is the 'Hawthorne effect': mere participation in an experiment can affect an individual's behaviour. Schwartz et al. (2013) show that the pure notion of being observed in the absence of any further incentives, instructions or help can reduce the energy consumption of households. Further, the effect vanishes upon a study's end. Other issues concern for example the correct sampling, assuring a representative test group for the general population, or eliminating participants' socially desired behaviour (Davis et al., 2013).

Methodological problems might therefore be a common issue in many study designs, leading to artificially inflated discount rates reported compared to actual rates in the general population. While this meta-analysis does not allow for a retrospective examination of all studies' methodological validity, the potentially most prominent issue of stated vs. observed discount rates can be analysed: do observations of actual behaviours (observed discount rates) differ from experimental elicitation procedures (stated discount rates)? For 132 reported discount rates a clear distinction of origin can be made. Stated discount rates (N = 50) have a higher median (34 %) and average (70 %) than observed discount rates (N = 82; median: 21 %; average: 43 %). Figure 2 is a graphical representation of this result. Nonetheless, statistically testing this difference reveals that the notion of significantly higher stated discount rates cannot be supported ($p = 0.321$)[2]. Hence, there is no evidence for the assumption that stated inter-temporal choices are significantly different to actual observed behaviour. I therefore assume that all reported discount rates have the same reliability.

Instead, the reported values' height might be a result of the risk attached to each inter-temporal choice, in conjunction with bounded rationality and limited capability to understand and assess risks in a financially appropriate way. Research on the relationship between risk taking and discount rates by van Praag & Booij (2003) found that a moderate negative correla-

1. The term 'average' describes the arithmetic mean throughout this paper if not noted otherwise.

2. The Mann-Whitney-U test is used, which is the strongest non-parametric statistical test for the null hypothesis that a particular population tends to have different values than the other. The choice of the Mann-Whitney-U test thus excludes any problems with differences in sample sizes or underlying probability functions. The U statistic is approximated with a normal distribution as the sample size is sufficiently large. The results of a one-sided test are presented. A two-sided test, i.e. testing for significantly different discount rates, is therefore also not significant as such event cannot have a smaller probability (in this case $p = 0.642$).

tion of -0.34 exists. This indicates that high risk-aversion goes hand in hand with low discount rates – something expected of prudent people, who take few risks and look a long time ahead. Indeed, specifically considering risk in the financial assessment of an inter-temporal choice usually decreases the discount rate: for example, Kooreman (1995) shows mathematically that assuming uncertainty in the actual lifetime of an investment, such as the life-time of a more energy efficient refrigerator, cannot increase the discount rate. Thus, the assumption of a deterministic lifetime as is done in normal NPV analyses might result in an upward bias of the discount rate. The intuitive explanation is that the possible benefit of a late failure does not offset the possible loss incurred at an early failure because 'late' is discounted more heavily than 'early'.

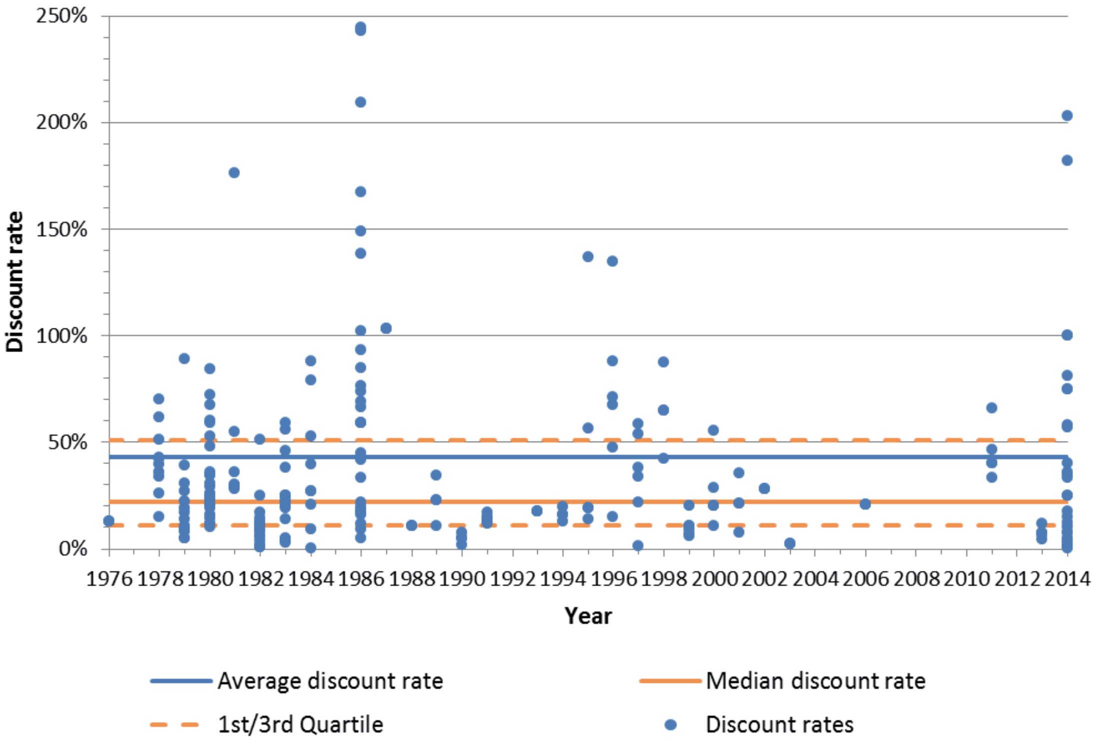

Figure 1. Presented are reported discount rates up to 250 %, including the average, median and quartile values. The variation in discount rates is clearly visible. There is no clear relationship between the value of the discount rates reported and their date of publication.

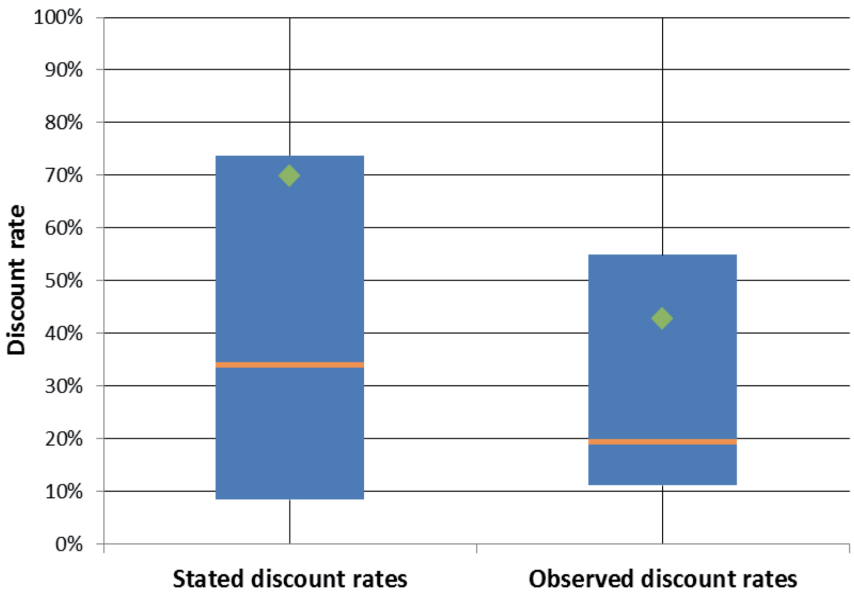

Figure 2. Presented are box plots of discount rates for stated and observed inter-temporal choices. The green chequers represent the average, the orange line the median and the borders of the box the first and third quartile. The variation in discount rates is clearly visible, but the difference is not significant.

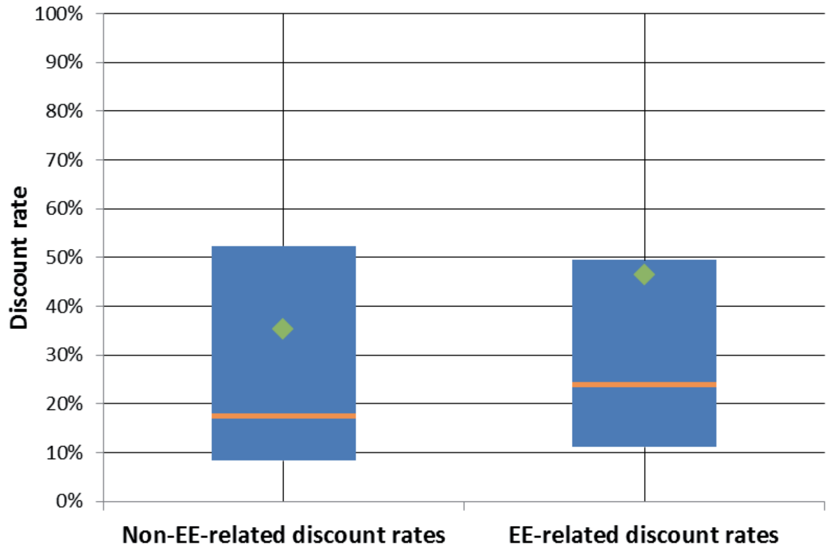

Figure 3. Presented are box plots of discount rates for investment decisions related to energy efficiency and unrelated investment decisions. The green chequers represent the average, the orange line the median and the borders of the box the first and third quartile. The variation in discount rates is clearly visible, but the difference is not significant.

Over and above the actual height of the discount rates observed, a specific concern for this paper is the question if there is a systematic and significant difference in inter-temporal decision making for energy efficiency investments compared to other investment decisions. In other words, do individuals behave differently when they decide on investments that will save energy? Or are they indifferent to the investment type?

Figure 3 gives an answer to this question by comparing discount rates of investment decisions linked to energy efficiency with those not linked to energy efficiency. Investment decisions specifically linked to energy efficiency are decisions such as on efficient appliances, housing insulation or fuel-efficient cars. General investment decisions from literature are often based on simple monetary choice observations, such as a lottery. The median (24 %) and average (46 %) discount rates are slightly larger for investments in energy efficiency (N = 139) than the ones not related to energy efficiency (N = 58; median: 18 %; average: 35 %). But the assumption that investments in energy efficiency have significantly higher discount rates cannot be supported, because the difference between both investment types is not significant (p = 0.184)[3]. The similarity in the distribution of discount rates is directly visible in Figure 3: the median and average values are well within the first and third quartile-boundaries of the other investment type. Therefore, the available data do not show that individuals apply systematically different discount rates to energy efficiency investments.

The variation in reported discount rates between but also within studies is striking and raises the question of its underlying drivers. One of the most prominent causes of variation seems to also influence the income level of individuals or to be the income level. Figure 4 gives an overview of discount rates per income level reported in literature. A correlation between high income levels and low discount rates can be observed. While it remains unknown what causes this relationship, several possibilities exists.

Wada et al. (2012) suspect that income itself is a cause, because low-income households do not trade-off common stock investments for energy saving investments due to low liquidity of available funds, i.e. the high initial investment costs are not feasible for low income households. Individuals with limited funds available might only chose investments with exceptionally high return rates as they do not have the funds to pursue a large number of investments. This selective behaviour could explain high discount rates, and indeed some research findings indicate that liquidity constraints contribute substantially to high discount rates (Arthur D. Little Inc., 1984; Epper et al., 2011; Fernandez, 2001; Houston, 1983; Min et al., 2014).

Another possibility is an underlying factor influencing income and discount rates: Enzler et al. (2014) are able to show that not only income but also education negatively correlate with discount rates. An explanation could therefore be that more education correlates with higher incomes (i.e. a university degree often pays off in terms of higher salaries) and lower discount rates (i.e. more education allows a better understanding of investment decisions). Lawrance (1991) estimates that discount rates are 3 % to 5 % higher for households with low permanent incomes than for those with high permanent incomes. Controlling for race and education widens this difference: with age and family composition held constant, discount rates for white, college-educated families in the USA are over 7 % lower than the ones of non-white families without a college education. These findings suggest that income has a direct influence on discount rates, but other factors such

3. The Mann-Whitney-U test is used again. The U statistic is approximated with a normal distribution as the sample size is sufficiently large. The results of a one-sided test are presented. A two-sided test, i.e. testing for significantly higher or lower discount rates in energy efficiency investments, is therefore also not significant and such event cannot have a smaller probability (in this case p = 0.368).

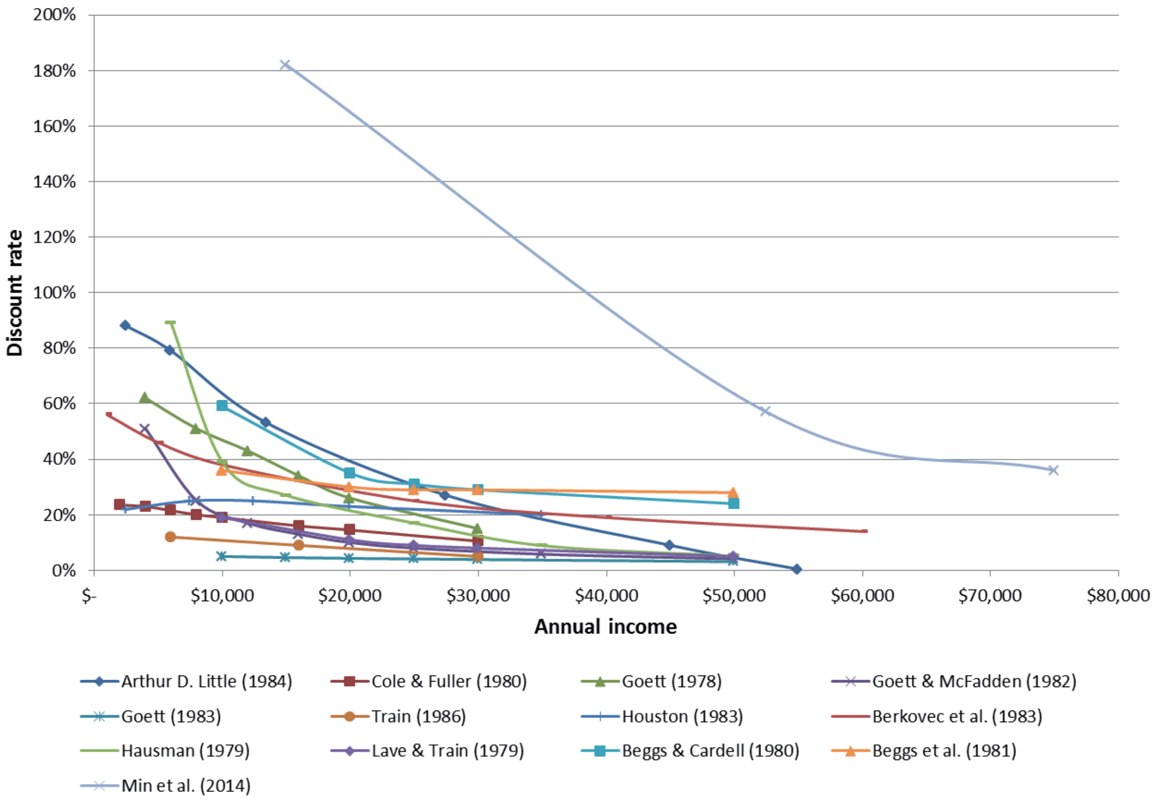

Figure 4. Shown is an overview of reported discount rates per income level. The income level is taken as the average of the reported nominal income classes or the anchor point for open-ended classes (e.g. income larger than $50,000). Most studies are from around the beginning of the 1980s, while Min et al. (2014) is more recent and hence uses higher nominal income classes due to inflation. Further, this study estimates discount rates based on investment in energy efficient lamps. The influence of the relatively small investment at question could explain the rather high discount rates reported. Nonetheless, a clear negative correlation can be observed.

as education exist that have a further effect on income and discount rates.

Not only income levels and education can vary inter-temporal decision making. Harrison et al. (2002) present a study with a sample taken from the Danish population. There, differences are visible for a whole set of demographic characteristics, which might either directly influence inter-temporal choices, or be linked to discount rates through a common, underlying factor. Again, education and income are powerful predictors for the discount rate, showing over a 10 % difference between more educated and less educated respondents. Further sources of variety, such as age, have also been reported in other studies (Fernandez, 2001; Train, 1985).

In addition, the situational circumstances in which an inter-temporal choice is taken have a strong influence. This notion is almost intuitive – it is the reason why marketing works. Sales tactics specifically (mis)use bounded rationality and social behaviour by making use of the human heuristics' shortcomings (Aronson et al., 2012). One of such sales tactics is advertising gains from investments as actual losses: "make the investment or lose money", meaning the loss of potential gains the investment could make. To be an effective tactic, it needs to influence our inter-temporal decision making, and in this case reflect the fact that I value potential losses higher than potential gains: Thaler (1981) shows that people discount financial losses, in this case traffic fines, much less than monetary gains of the same value. Many other studies reproduced such findings (Frederick et al., 2002; Loewenstein, 1987; Redelmeier & Heller, 1993; Sorrell et al., 2010).

Similar behaviour can be observed if an inter-temporal choice involves a change to a non-monetary less favourable situation. An experiment by Sunstein & Reisch (2014) evaluating the willingness to switch to a "green energy" supplier shows that individuals are willing to switch to such provider for half the amount they need to receive to be convinced to switch away from such provider. Further, their results indicate that those who are less educated are more likely to stick with the default option they get offered for investments.

Many more situational influences have been reported in literature: for example, Loewenstein (1988) finds that the timing of an outcome is much less important, i.e. the discount rates are much lower, when respondents evaluate a single outcome at a particular time than when they compare two outcomes occurring at different times, or specify the value of delaying or accelerating an outcome.

O'Donoghue & Rabin (2001) explore procrastination in inter-temporal choices. They show that a person might never carry out a very easy and very good investment, because they continually plan to carry out an even better but more onerous one. Extending this logic, they show that providing people with

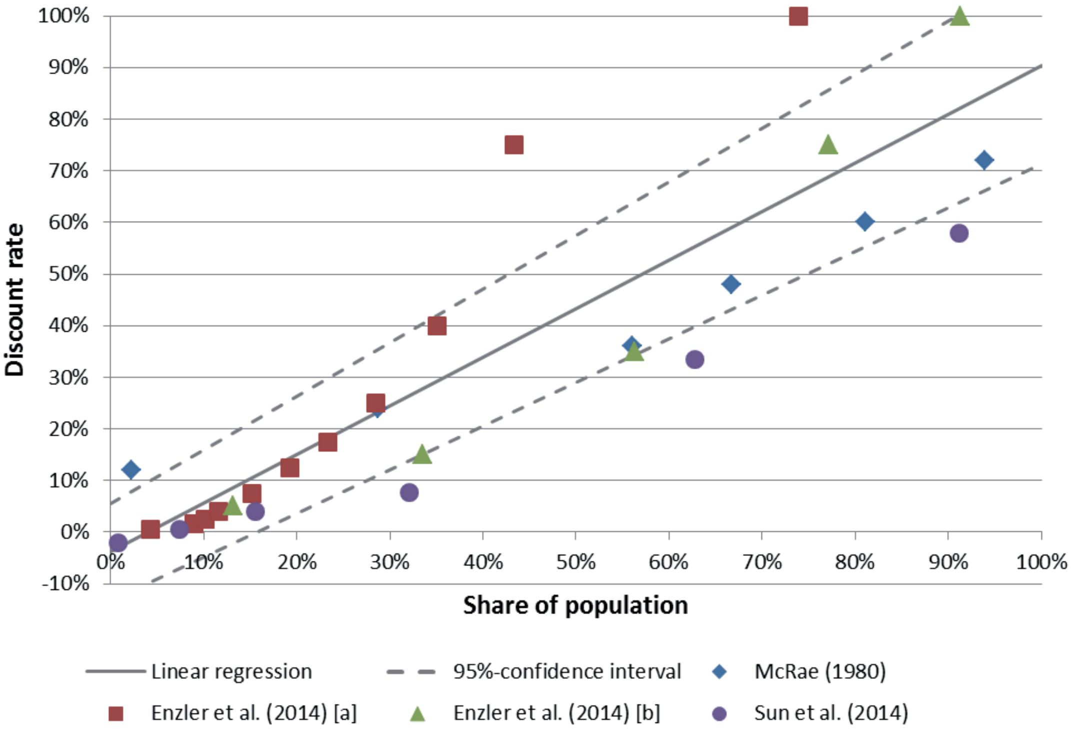

Figure 5. Overview of the share of the population exhibiting a maximum discount rate with 100 % as possible maximum. The data points are positioned in the middle of the reported population intervals. Surprisingly, a small fraction of the population appears to show negative discount rates, i.e. making investments that will never pay off. This could be explained with the notion that some benefits of a monetary investment might be non-monetary or the bounded rationality of market actors. While exponential functions fit each single data series better, the whole data range has the highest coefficient of determination for a linear fit. Enzler et al. (2014) present two data series which are presented as [a] and [b].

new options might make procrastination more likely. Even if an investment appears to be favourable, a better one might just wait around the corner.

Frederick et al. (2002) report that the perspective on inter-temporal choices always matters: implicit discount rates are dramatically higher when I generate the future reward that would equal a specified current reward than when I generate a current reward that would equal a specified future reward. Further, small amounts are discounted more than large amounts, potentially because the bounded rationality of individuals uses simple heuristics for decisions with low impact (small amounts) and more detailed analysis mechanisms for high-impact investments (large amounts).

Another striking result is the time dependence of observed discount rates. Thaler (1981) asked subjects to specify the amount of money they would require in one month, one year or ten years to make them indifferent to receiving $15 now. The median responses imply an average discount rate of 345 % over a one-month horizon, 120 % over a one-year horizon, and 19 % over a ten-year horizon. In other words, someone may prefer €10 in 11 days over €5 in 10 days, but also prefer €5 now over €10 tomorrow. The dependence of discount rates on time periods is a common finding in literature (Epper et al., 2011; Train, 1985), and often described as 'hyperbolic discounting' as the discount rates' dependence on investment's time periods follows a continuously declining hyperbola. Interestingly, hyperbolic discounting can lead to "strategic ignorance" – a person with hyperbolic discounting, who is worried about withdrawing from a previously decided investment when the costs become imminent, might choose not to acquire information, even if provided for free, if doing so increases the risk of bailing out (Carrillo & Mariotti, 2000). Once an inter-temporal decision has been made, additional information is actively ignored to not endanger the original choice.

Somewhat surprisingly, the actual discount rates for a specific inter-temporal choice appear to be moderately stable over time (Enzler et al., 2014). Only a small variation in the discount rates is observed if individuals are confronted with the same inter-temporal choice today, tomorrow or in a year. Nonetheless, their time-dependent variation is larger than usually found in personality traits, thus indicating a possible instability over time.

All the above mentioned factors contribute to the understanding that no single discount rate exists. On the contrary, literature suggests that each individual uses an individual discount rate, influenced by situational and personal constraints. Three studies were found to look at the distribution of discount rates for a common inter-temporal choice in detail (Enzler et al., 2014; McRae, 1980; Sun et al., 2014). Figure 5 visualises this spectrum of discount rates in the population based on previous research findings. A clear variation of discount rates is directly visible. A linear regression yields that each incremental 1 %-percentile of the population has on average a 0.904 % higher discount rate than the previous percentile[4].

Following this, half of the population should have a discount rate of 45.8 % or higher, which is near the average discount rate but larger than the median discount rate, presented in Figure 1. The linear regression further shows that 78 % of the observed variation in discount rates can be explained by the variation of individuals in the population; around 22 % of the variation has other sources such as the type of inter-temporal decision faced. While the curvature of some individually observed discount rates per study seems to suggest that a non-linear fit might yield even better results for each specific inter-temporal choice, the linear fit offers a good explanation of variation and highly significant results in the absence of a known non-linear relationship.

Inter-Temporal Decision Making of Legal Entities

Individuals are only one kind of economic actor; legal persons such as companies are an inherently different but yet related type. In every firm one or multiple bounded rational individuals take the actual inter-temporal decision. But the potential for institutionalising decision making according to pre-defined processes such as financial risk management, and the usually larger amount of resources spent on information gathering and expertise accumulation should lead to economically more optimal inter-temporal decisions compared to individuals, potentially circumventing the limitations of people's bounded rationality.

The discount rates exhibited by firms should therefore be different to those of individuals, if their decision making processes allow for a better financial assessment. Unfortunately, the literature on discount rates of legal entities is much scarcer than that for individuals. One of the reasons might be that stated preference experiments (common with individuals) are not possible for companies but only actors within companies. Further, often a firm's inter-temporal decisions are business sensitive and not openly accessible, and information on the underlying decision making processes are unavailable. While this complicates research efforts, it does not per se prevent researchers to represent and evaluate each inter-temporal decision made by these firms within the DU model.

I identified four studies reporting discount rates of energy efficiency related investments in the commercial sector (Alcorta et al., 2014; Harris et al., 2000; Qiu et al., 2015; Ross, 1986). These studies cover in total 32,273 energy efficiency investment projects with an overall capital investment of approx. €1.5 billion. Most of these investments are undertaken by small- and medium-sized enterprises (SMEs), and only 1.2 % by large manufacturing companies. The geographical coverage includes the USA, Australia and developing countries. The average discount rate of all investments is 46 % (minimum reported discount rate: 4 %; maximum reported discount rate: 111 %; no median reported).

Overall, these 32,273 investments represent only ca. 47 % of all profitable energy efficiency investments recommended to the firms by external auditors (Alcorta et al., 2014; Harris et al., 2000; Qiu et al., 2015; Ross, 1986). This raises the question: why do companies not invest into more or even all profitable projects?

The average discount rate of legal entities is in the range of the average discount rate of individuals (43 %). Hence, a reason could be that most investments are by SMEs which do not have the necessary resources to significantly improve the decision making process compared to individuals. Indeed, it would make sense to assume similar discount rates if only one single, boundedly rational individual (potentially the owner) takes the decision for the SME.

Further, there is a clear difference according to budgeting rules and therefore investment decision making process applied within a firm (Moya et al., 2011; Ross, 1986): companies with flexible budgeting rules exhibit lower discount rates than the ones with strict capital rationing rules. In the latter case each business unit has a fixed budget. If this budget is fully allocated, no further profitable energy efficiency measures can be undertaken, even if other business units do not offer investments with the same profitability. Strict capital rationing is more common in firms that are comparatively weak financially, but can reduce the overall profitability of a firm.

On average, smaller investment projects are usually more highly discounted than large capital investments: for large manufacturing companies, small investment projects were discounted at around 35 %–60 %, medium-sized investment projects at 25 %–40 %, and large-sized investments at 15 %–25 % (Ross, 1986). A qualitatively similar trend can be seen in energy efficiency investments by SMEs (Qiu et al., 2015). A plausible reason could be that companies spend more resources on the investment decision for large projects, because the financial risk is larger. Or these large projects are vitally important to the core business of a company, which requires firms to accept comparably less profitable investments (Cooremans, 2012). In general, most investment decisions in firms are a result of applying a set of fixed rules rather than a systematic financial analysis with an investment's profitability as necessary but insufficient decision criterion and including a comparison to alternatives (Cooremans, 2012; Sorrell et al., 2000).

Qiu et al. (2015) indeed show that investments directly improving SMEs' core business, such as productivity improvements, are significantly more often undertaken than similar ones offering only energy savings. Thus, companies discount pure energy saving measures more, even if they have the same economic viability as other investments, which is a result expected from boundedly rational decision makers and an indication that, contrary to the neoclassical theory of the firm, intrinsic characteristics of a company affect its decisions on energy efficiency investments (DeCanio & Watkins, 1998; Schleich & Gruber, 2008). Other reasons for high discount rates include the owner/employee-dilemma, where, similar to the investor/user-dilemma, the employee of a company is optimising her actions in line with her strict performance evaluation criterions such as increasing sales numbers rather than reducing costs; this notion is supported by the observation that the reduced or missing need for profitable investments of legal entities in public or quasi-public ownership exhibit the most barriers to energy efficiency investments (Schleich & Gruber, 2008).

4. The linear regression is based on a least-square fit. The presented fit is highly significant ($p = 3.927 \times 10^{-10}$) and the coefficient of determination $R^2 = 0.784$ shows a good predictability of outcomes.

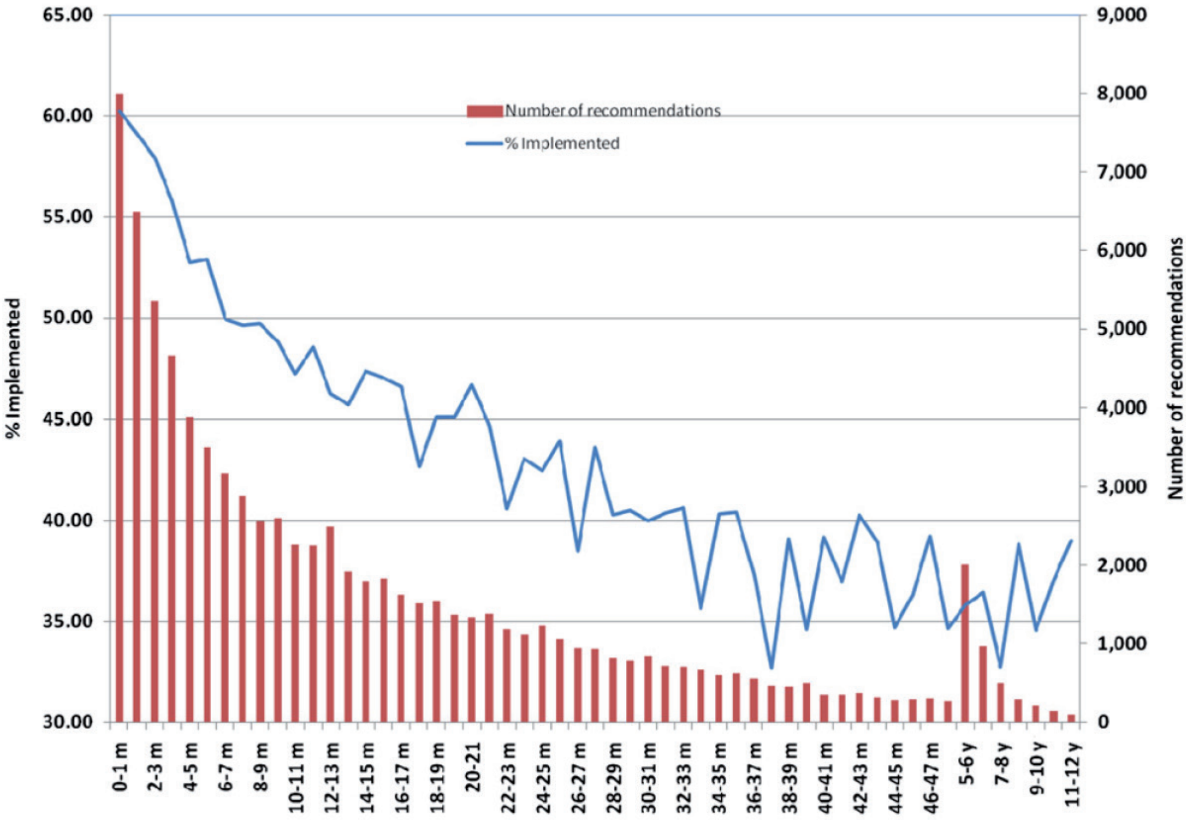

Figure 6. Shown are the payback periods of profitable energy efficiency investments (right axis) and their implementation rate (left axis) from the Industrial Assessment Center Program. The implementation rate drops below 50 % at a payback period of less than six months. Source of the Figure: Abadie et al. (2012).

The absence of financial risk assessment procedures for energy efficiency projects appears to be another hindrance for effective investment decisions. Research shows that many companies rely on simple payback rules rather than standard NPV calculations or the more sophisticated methods such as 'value-at-risk' that are common in the financial industry (Abadie et al., 2012; Jackson, 2010). For example, nine out of ten surveyed firms in developing economies use only simple payback rules to assess the financial viability of energy efficiency investments (Alcorta et al., 2014).

Given these limited rules-of-thumb, the low risk of energy efficiency investments or their potential to offset risks of energy price volatility is usually overlooked (Jackson, 2010). Moreover, some research suggests that energy efficiency investments can provide a significant boost to a firm's productivity (IEA, 2014; Worrell et al., 2003). Including the productivity benefits explicitly in the economic assessment would double the cost-effectiveness of energy efficiency investments compared to an assessment without productivity considerations. In the light of companies' greater willingness to invest in core business related projects (Schleich & Gruber, 2008), the effect on accepted discount rates of a more accurate estimation of the impact of energy efficiency investments would be even greater.

As a result of this inadequate investment assessment, many companies require very short payback periods for energy efficiency investments to have a large but irrational 'safety margin' without any further economic rationale (Jackson, 2010; Schleich & Gruber, 2008; Thollander & Ottosson, 2008). Data on firms in developing countries show a remarkably universal threshold payback period of below two years, a rate required by small Peruvian textile companies as well as large Colombian metal producers (Alcorta et al., 2014). In the USA, required payback periods by SMEs are even smaller and average less than a year for energy efficiency investments (Abadie et al., 2012; Qiu et al., 2015). Figure 6 gives an overview of the payback periods of profitable energy efficiency investments and the rate at which these still get implemented.

Given the reported importance of simplistic payback rules-of-thumb in corporate decision making, it is worth looking at the relationship between discount rates and threshold payback periods in more detail. For this, I assume an idealised investment where all costs are paid upfront as invested capital R_T with no further costs during the investment's lifetime T. Further, the total return on the investment R is evenly spread out over the investment's lifetime, yielding an annual cash flow of savings $R_T = R / T$. Thus, the discount rate d is exactly the rate at which the future savings equal today's investment in the NPV calculation:

$$I = \sum_{t=1}^{T} \frac{R_T}{(1+r)^t} \tag{4}$$

The undiscounted payback period of such an investment is $P_T = T \times I / R$. Using the equality of investments and discounted

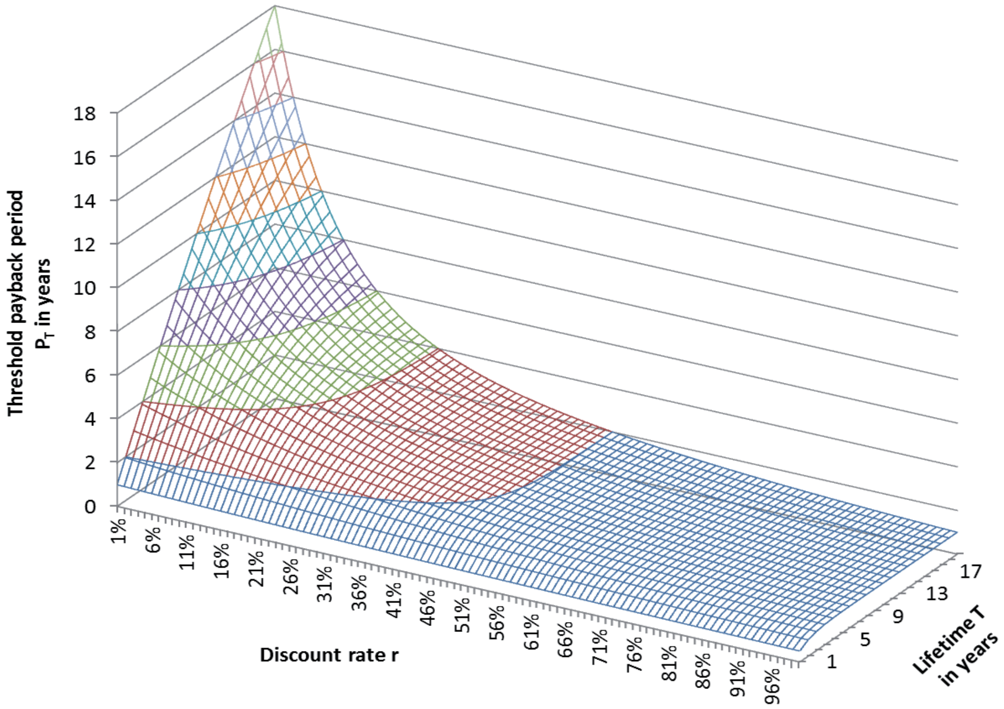

Figure 7. Presented is the simple threshold payback period P_T for an investment with a lifetime T and corresponding to a discount rate r. The colour boarders represent two-year-increments in threshold payback periods. Long payback periods correspond to low discount rates, which are only exhibited by few economic actors.

returns from above, the corresponding threshold payback period becomes:

$$P_T = \frac{I}{R_T} = \sum_{t=1}^{T} \frac{1}{(1+r)^t} \tag{5}$$

The threshold payback period therefore depends on the lifetime T of an investments as well as the discount rate r.

While no algebraic solution exists, it is possible to estimate numerically the corresponding threshold payback periods for a given discount rate. Figure 7 gives an overview of threshold payback periods corresponding to discount rates from 0 % to 100 % for investment lifetimes ranging from one to 20 years. If a payback period of two years or less is required according to the financial rules of a legal entity, the non-undertaking of many long lifetime investments, which are typical for energy efficiency, implies high discount rates of 30 % and above.

These results should be used with caution and only seen as indicative. The underlying assumptions are strong and rarely satisfied in real investments, because the usual cash flow of any investment into a physical structure entails running costs such as maintenance costs or debt payments, which would then need to be discounted appropriately, too. Hence, this idealised investment is only an approximation of reality to give a qualitative insight into the relationship between discount rates and threshold payback periods. In addition, some firms have threshold discounted payback periods, therefore looking at the time which an investment needs to pay back with discounted returns. While the above presented relationship contains a discount rate, it does not compare discount rates with discounted payback periods. Thus, it cannot be used to compare discount rates presented in literature with discounted payback periods.

Threshold Discount Rates for Investments in Energy Efficiency

After presenting the discount rates of different economic actors, this paper now turns to the required threshold rates for typical investments in energy efficiency.

The preparatory studies for implementing measures under the Ecodesign Directive are a rich source of data on investments' required discount rates (European Commission, 2015). Following a common methodology, each preparatory study constructs a base-case representing an average product on the market in terms of resource efficiency, emissions and functional performance. The base-case is not necessarily an actual product one can buy on the market; it is rather a 'virtual product' representing an average sales-weighted product, especially when the market is made up of different technologies. Different technology options, usually representing a mix of similar products, are then evaluated against the base-case to determine the potential for ecodesign requirements (COWI Belgium & VHK, 2012).

Assuming the price premium of a more efficient technology is an investment, the energy savings can be monetised and treated as revenue from this investment decision. Further, using the identity of the DU model in the NPV representation, the internal rate of return (IRR) of such an investment equals the threshold discount rate. That is, someone investing in the more efficient product must have a discount rate equal to or below the IRR, while someone not investing has a discount rate above the IRR.

The use of 'virtual products' imposes certain limitations on these threshold discount rates, because the difference in individual usage patterns, retail prices and energy prices are 'averaged out'. Further, some product groups might, at first sight, seem to offer an investment opportunity for more efficient products, which are usually not completely identical in function. An example is lamps: while in many situations a light emitting diode (LED) lamp can replace an incandescent lamp, they do not work well with most dimmers. Hence, a consumer requiring this function has not this investment choice. In addition, the methodology of preparatory studies does not usually provide for detailed sales numbers, which would be necessary to estimate the share of product buyers above or below the threshold discount rate. This data are therefore not directly comparable with reported discount rates from literature.

However, these IRRs can be used to compare reported discount rates from literature with actual energy efficiency investment opportunities. In total, 59 IRRs were extracted from the preparatory studies for investments in products of mid-level efficiency (approx. in-between the base-case and the best available technology) (European Commission, 2015). The average IRR is 52 % while the median is 10 %, showing the existence of a small number of high IRRs in the data. Figure 8 illustrates this in a box-plot. The first quartile is at -1 %, because 17 of the 59 IRRs are negative.

How many investments in efficient technologies are then made? The median IRR of 10 % is near the first quartile of individuals' discount rates reported in literature (11 %, see Figure 1), hinting that only a minority of people might take the investment decision for energy efficient technologies. In a more detailed analysis, I match the IRRs of efficient technologies with the discount rates exhibited in the population (see Figure 5); the IRR is the threshold discount rate and determines the share of the population (with a lower discount rate) that would in principle be willing to make such an investment. Figure 9 gives an overview of the fraction of possible investments actually made per quantile of population. The average expected investments are fitted best with an exponential decay, showing that it is unlikely anyone would be ready to invest in all mid-level technologies. Further, half of the population would probably buy less than thirteen out of 59 mid-level efficient products.

If one is ready to make the assumption that these 59 investment options are a rough but valid representation of all investment opportunities in energy efficiency, Figure 9 further yields information on the size of the energy efficiency gap, because the area below the average investment fit corresponds to the fraction of investments undertaken: only ca. 27 % of all possible energy efficiency investments are actually made. Nevertheless, this includes a number of investment opportunities with a negative IRR. Focusing on investments with a positive return on investment, ca. 42 % of these are undertaken. Further, assuming a WACC of 5 %, the percentage of undertaken investments with a positive return rises to around 47 %. Even when requiring an IRR above 17.5 %, only approx. 60 % of all viable energy efficiency projects get financed.

The Impact of Public Policy

The data presented here are a strong indication that the energy efficiency gap actually exists; as a result, economically beneficial investments are not undertaken. This leads to market inefficiencies and affects the security of the Union's energy supply. Furthermore, it appears that not low rates of return on energy efficiency investments, but extensively high discount rates of individuals, are a barrier.

One way to reduce the energy efficiency gap is by promoting beneficial investments through public policy. Implementing measures under the Ecodesign Directive are one example (European Commission, 2015): these regulatory measures prohibit the placing of the most energy inefficient products on the European market. The designated target level of efficiencies equals the least life-cycle cost, ensuring that individuals pur-

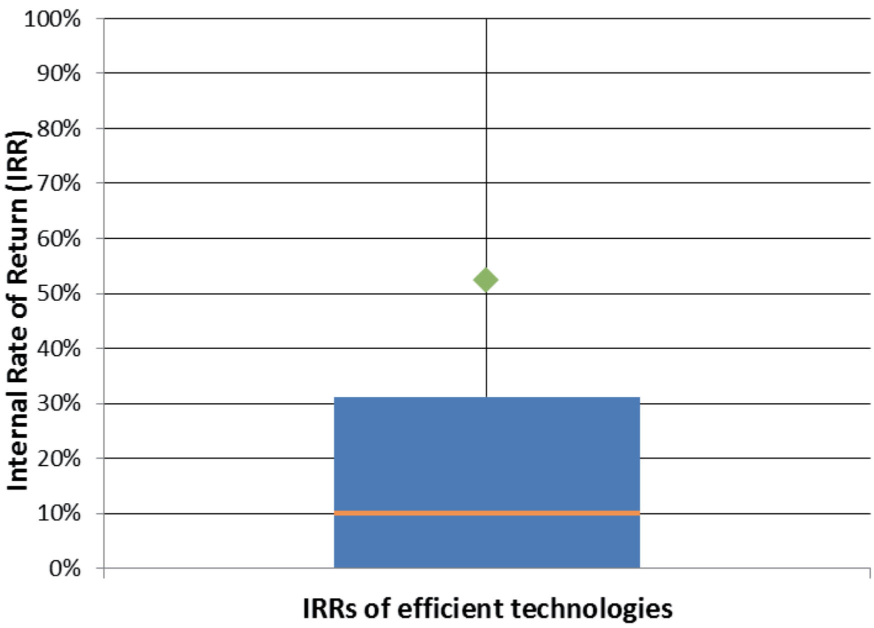

Figure 8. Presented are the IRRs for investments in products with mid-level efficacy. These equal the threshold discount rates for investment decisions (N = 59; average: 52 %; median: 10 %, Q1: -1 %; Q3: 31 %).

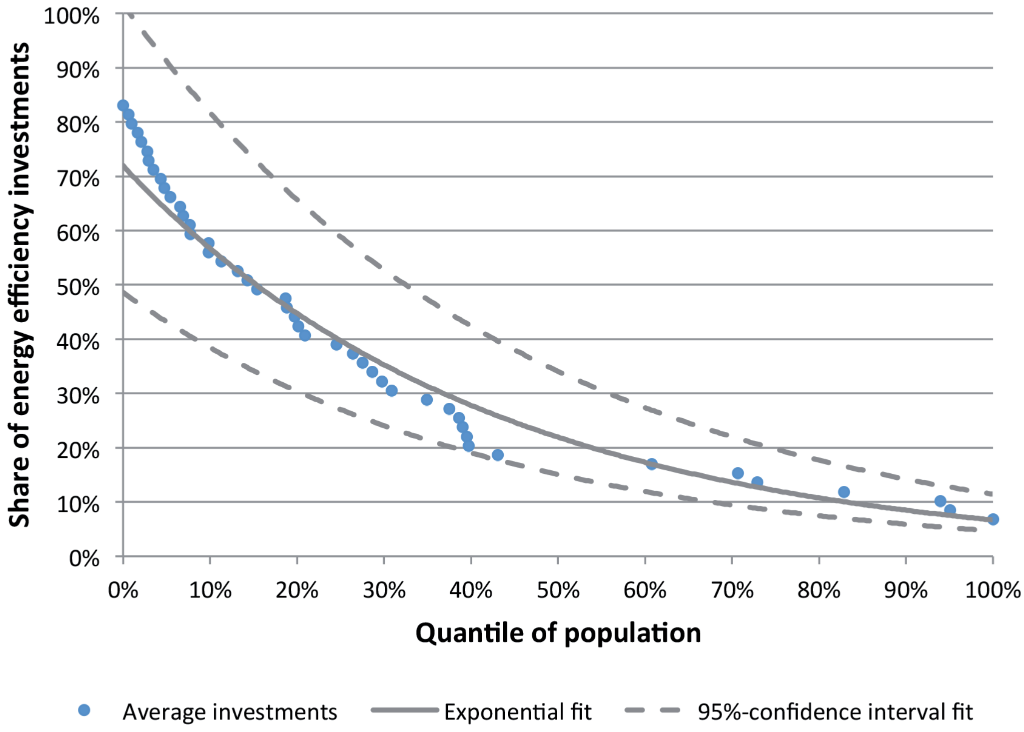

Figure 9. Shown is the quantile of the population which would invest in the respective share of mid-level efficient products. The average investment numbers are derived using the linear regression of the discount rates in the population (see Figure 5) and the IRRs from the Commission's preparatory studies (European Commission, 2015). The exponential least-square fit yields a decay proportional to -2.4 times the current share of investments. The high coefficient of determination $R^2 = 0.968$ indicates a good quality of fit. The 95 %-confidence interval fit is based on the confidence interval of the linear regression of the discount rates in the population.

chase the economically most viable product or, if they desire, more energy efficient ones. This policy therefore circumvents the problem of high discount rates.

In the USA, the 'Industrial Assessment Center Program' funded by the US Department of Energy is an example of promoting energy efficiency in industry. These 24 centres are located at US universities and have the two-fold purpose of offering free energy audits to SMEs while at the same time training future energy auditors. Tonn & Martin (2000) show that SMEs undertake significantly more energy efficiency investments after this free energy audit. Some companies even changed their general prospect towards energy efficiency, for example by establishing an energy conservation programme or including energy-consideration measures into future planning processes.

A different approach is to legally require energy efficiency improvements but let individuals or firms decide on the appropriate investments to reach a certain goal. The EU encourages Member States to opt for such obligation schemes with its Energy Efficiency Directive. These schemes could result in demand-side management programmes common in the USA, which root back to the 1970's oil crises. These programmes are funded through energy bills and require utility providers to achieve certain energy savings. Arimura et al. (2011) present a meta-analysis of these programmes to evaluate their economic effectiveness, and provide an overview of cost estimates based on three separate models, which all achieve similar results: each kWh of electricity saved cost the utility provider 3.0 cents (standard error: 1.8 cents). In comparison, marginal costs per new kWh of electricity are around 9 cents for new base-load capacity and over 13 cents for peak-load capacity (National Academy of Sciences, 2010).

The costs to the consumer are usually higher than just their contribution through energy bills, because demand-side management programmes often only offer a contribution to investments in energy efficiency. It has been estimated that the sum of all costs to consumers is roughly 1.7 times utility costs alone (Nadel & Geller, 1996; Nadel & Kushler, 2000). With an average retail price of 9.1 cents per kWh of electricity (Arimura et al., 2011), the IRR for a consumer undertaking an energy efficiency investment under this programme is above 78 % for a project lasting one year and falls to a little over 6 % for a twenty-year project, which is realistic for large investments such as the heating systems of buildings. Even when assuming the upper limit of 4.8 cents per kWh utility costs, these IRRs become 12 % and 1 % respectively and are therefore still profitable energy efficiency projects (excluding WACC).

Another way is to directly act on individuals' inter-temporal decision making with a view to reducing the discount rates exhibited by them. Logically, interventions would need to address the shortcomings experienced by individuals. In general, assessing the costs and benefits of energy efficiency is an imprecise art. But this is a general problem in cost-benefit analysis, not a special problem in evaluating energy efficient technologies. Providing easily understandable information can be a first step towards overcoming natural cognitive constraints, and research has proven its effectiveness.

Min et al. (2014) look at the impact of making individuals aware of a product's lifetime costs by using labels attached to lamps. On average they found that providing operating cost information induces stronger preferences for lamps with longer lifetime and lower energy consumption. Observed discount rates decreased from over 560 % to around 100 % when annual operating cost estimates were provided. This effect was strongest for individuals with a high household income.

Sammer & Wüstenhagen (2006) show that the energy efficiency information presented to an individual has profound consequences on consumer product choices. Using the EU's energy label in an experimental setting with stated preferences, consumers were willing to pay a €456 price premium for an 'A'-class labelled washing machine compared to a 'C'-class labelled one (ca. 30 % of the average washing machine price in Switzerland), and a €4 price premium for an 'A'-class labelled light bulb compared to a 'C'-class lamp (ca. 60 % of the average lamp price in Switzerland). Taking these retail price premiums as investment with reduced electricity costs and longer life-time as returns, the NPV calculation yields an IRR of -5 % for the switch to efficient washing machines and 186 % for the switch to efficient lamps. These results are remarkable in two ways: first, the energy label for washing machines made participants take an investment with an IRR vastly below their usual discount rate, leading to a choice in which they would lose money. Second, while the relative premium spent on lamps was double that on washing machines, participants still underestimated significantly the savings potential of more efficient lamps and required an excessively high discount rate.

The Commission services recently issued an evaluation of the effectiveness of the current European energy label and possible alternative versions (London Economics, 2014). An online experiment indicates that a majority of consumers is willing to pay a considerable price premium for appliances with a higher energy efficiency class. Figure 10 shows the results in price premiums for three product groups. Testing these results for televisions and washing machines in physical shops throughout the EU, the study presents data on observed consumer buying patterns in relation to the energy efficiency of labelled products, which I use to derive the discount rates for these investment decisions with the IRR calculation in the NPV identity of discount rates compared to the investment with the lowest retail price. The IRRs of the investment decisions are, by definition, the minimum discount rate an individual applies in the inter-temporal investment decision. Table 1 presents the results of this exercise as well as the corresponding share of consumers willing to make this investment and the expected share based on reported discount rates in literature. Most interestingly, consumers take investment decisions on labelled products with significantly lower discount rates than previously reported in literature. In all cases, the observed share of the population exhibiting a certain minimum discount rate is well above the 95 %-confidence interval of expected observations.

While the study does not provide for an experimental setting to directly assess the impact of the energy label, it is reasonable to assume that the additional information through the label helped consumers make a more informed purchase decision, therefore acting on the bounded rationality of individuals. If the energy label is the only variable to explain the difference in expected and observed behaviour, it reduces the individuals' applied discount rate on average by 46 % (see Table 1). This is the strongest possible observed effect of energy labelling, which might in reality be between this point and no effect.

Research on energy performance certificates for buildings in the EU also indicates a positive, but lower effect: in Austria, a higher energy efficiency class can increase property prices by around 12 %, while in Belgium this relates to only a 3 % price premium and in parts of the UK almost no effect can be found (Bio Intelligence Service et al., 2013). These intra-EU differences could stem from the differences in the calculation as well as design of certificates, because the EU's Energy Performance of Buildings Directive allows Member States much freedom in the implementation of the mandatory certificates. Further, in regions with less ample supply of housing like London in the UK, criteria such as the energy performance of buildings may attract less attention from prospective buyers, because the restriction in choice forces a concentration on other, more important criteria such as location or size (Fuerst et al., 2013).

Another possibility to influence inter-temporal choices is by adjusting the future utility. For example, increasing energy taxes makes investments in energy efficient products more profitable. But findings from literature suggest a surprisingly limited effect. Cohen et al. (2015) found an estimated elasticity of increased energy prices through energy taxation on electrical appliances of -0.16. That is, a 10 % increase in the price of electricity only reduces the average annual electricity consumption of sold appliances by 1.6 %, because most of the energy cost increase is compensated by reduced retail prices of high energy consuming models relative to energy efficient ones. Manufacturers and retailers are able to absorb energy tax

Table 1. Presented are the observed minimum discount rates derived through the IRR calculation of comparing a top-efficacy investment option and a mid-efficacy investment option with a low-efficacy investment option (London Economics, 2014), in conjunction with the observed share of consumers agreeing to undertake an investment with this or a lower discount rate. The expected minimum discount rate for the observed share of consumers and the expected share of consumers for the observed minimum discount rate are shown for comparison (with 95 %-confidence interval).

Washing machines

	Observed DR	*Expected DR*	*Observed share*	*Expected share*
Top-efficacy option	1 %	35 % (17 %–52 %)	43 %	5 % (0 %–19 %)
Mid-efficacy option	10 %	68 % (44 %–93 %)	80 %	15 % (4 %–32 %)

Televisions

	Observed DR	*Expected DR*	*Observed share*	*Expected share*
Top-efficacy option	-18 %	25 % (10 %–41 %)	32 %	0 % (0 %–0 %)
Mid-efficacy option	-4 %	57 % (35 %–80 %)	68 %	0 % (0 %–13 %)

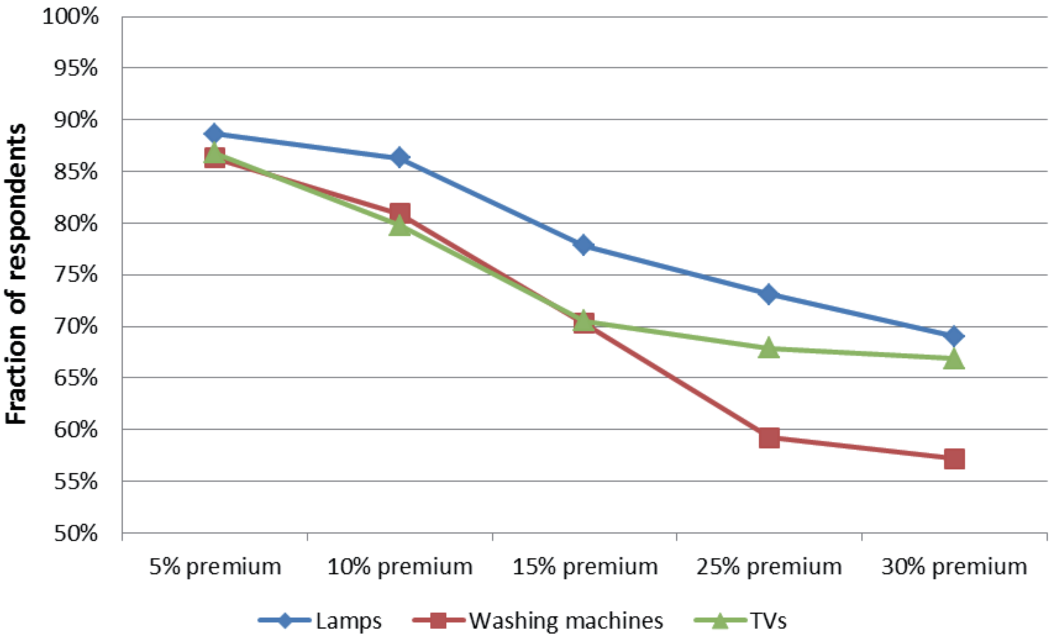

Figure 10. Presented is the share of respondents willing to pay a retail price premium for a more energy efficient product labelled with the EU's energy label (London Economics, 2014).

shocks by cutting prices as imperfect competition driven by product differentiation leaves them with substantial profit margins. The lowered investment costs therefore reduce any impact on discount rates to a minimum.

A similar but less pronounced example of the possible effect of energy taxation is provided by Allcott & Wozny (2013), which show that individuals are indifferent between $1 in future fuel costs or $0.76 in vehicle purchase price. Hence, a policy aiming to reduce fuel consumption should provide for mandatory measures internalised into the vehicle's retail costs, because consumers are more willing to accept higher fuel costs. In this way, more energy savings could be realised with the same economic cost to consumers. Another finding is that individuals only respond to fuel price changes with up to a six-month delay (Allcott & Wozny, 2013). Thus, individuals use the information on decreased life-time costs to adjust the amount of money they are willing to invest, but their bounded rationality leads to economically inefficient behaviour.

Informing individuals seems to only work if the information is about contextual factors such as energy consumption, energy prices or product life-times. Information about best practices or one's own energy consumption without further context, for example aimed at a voluntary change of an individual's behaviour, shows only little effect (Mills & Schleich, 2010). These types of information appear to result only in higher knowledge levels without measurable relevance to individuals' behavioural changes (Abrahamse et al., 2005). Nevertheless, a meta-analysis of research on information strategies indicates that individual energy audits are comparatively more effective than peer comparison or monetary feedback (Delmas et al., 2013). Public policy aiming for increased consumer awareness or behavioural adaptations should be well designed and address these potential shortcomings to be effective.

Reducing the risks of investment in energy efficiency is often cited as another tool to decrease discount rates. But the argument that high discount rates can be considered a rational response to risk for all types of energy efficiency investment does not seem to be plausible. For example, it cannot be explained why cost-saving energy efficiency investments should be subject to more stringent investment criteria than other equally illiquid and irreversible investments (Schleich, 2007). According to neoclassical economic theory, investors should be willing to accept a lower than market return on energy efficiency investments in return for the ability to reduce risk in their overall portfolio (Howarth & Sanstad, 1995; Metcalf & Rosenthal, 1995). But the observed lack of these investments corresponding to the energy efficiency gap indicates that factors such as bounded rationality might prevent optimal economic behaviour, and neoclassical economic theory cannot sufficiently explain the observed behaviour of economic actors. Hence, public policies specifically reducing the risk of energy efficiency investments might not deliver the desired results.

Conclusions

The available literature devoted to inter-temporal choices expressed in the DU formulation contains valuable insights into discount rates. But it has failed to establish any stable estimate of one, universal discount rate. There is extraordinary variation across studies, and usually even within studies. Thus, there is no reason to expect that discount rates should be consistent across different choices or individuals. Even more, research indicates that there is reasonable doubt that individual discount rates have an impact on actual energy saving behaviour or could be used as a reliable predictor (Enzler et al., 2014). Discount rates are a theoretical construct covering multidimensional personality traits, habits and biases; a change in one's individual discount rate according to choice, individual experience, personality and situational framing is only natural to assume.

Hence, the empirical evidence has called virtually every assumption of the DU model into question (Frederick et al., 2002): for example, the previously presented assumption of constant discounting over time has been rejected by a large proportion of studies. Only under very specific assumptions can the DU model in its NPV-like representation be used in economic modelling to explain or predict an individual's behaviour.

Nonetheless, the data presented here offer valuable insights and allow for a better understanding of individuals' investment behaviour if one is willing to accept the limitations of the DU model. Given the large number (204) of unique discount rates used, it is likely that the individual discount rate most individuals might exhibit in any possible investment situation is covered and roughly follows the distribution derived in the Results section.

As a general result, discount rates do not converge on the prevailing market interest rates, but instead are much higher. This would, at first sight, indicate that many individuals are neglecting capital markets. Applying, for example, the WACC as discount rate in the DU model usually overestimates the actual willingness to make a positive investment decision. On the other hand, applying the behavioural discount rates from the DU model in the NPV calculation will significantly underweight future benefits. As a result, the empirical evidence clearly shows that behavioural discount rates should not be used to evaluate the financial viability of an investment decision.

Lack of sufficient information, constraints on financial resources and limited cognitive capabilities, expressed as bounded rationality, are usually cited as reasons for the large variety of discount rates (Frederick et al., 2002; Train, 1985). These constraints can explain the observed regularities:

- gains are discounted more than losses;
- small amounts are discounted more than large amounts;
- greater discounting is shown to avoid delay of a good than to expedite its receipt;
- many socio-economic aspects such as income, age or education have a significant influence on exhibited discount rates;
- discount rates are moderately constant over time but not over time periods, where they appear to decline (hyperbolic discounting); and
- risk aversion appears to have a decreasing effect on discount rates.

To what extent are these insights helpful or even crucial for policy makers? First, the overview of exhibited discount rates matched with the necessary ones for energy efficiency investments indicates a large energy efficiency gap between the number of economically desirable investments and actually undertaken investments. The approach presented here estimates that approx. 53 % of all energy efficiency projects with a return on investment equal or larger to WACC are not undertaken by households. This has profound implications for the optimal allocation of resources and eventually Europe's security of supply with fossil fuels.

Second, public policy needs to act on the underlying constraints to reduce the energy efficiency gap. Here, literature suggests that the current energy efficiency policies of the EU offer suitable tools to act on various aspects: ecodesign and performance standards for cars and buildings remove the worst performing products from the market, therefore forcing economically beneficial investments. Energy labels and energy performance certificates, which provide individuals with information on the energy performance of appliances, cars and buildings, have been able to mitigate investment inefficiencies by acting on the information deficits linked to individuals' bounded rationality.

In addition, the results from literature provide information on how to improve energy efficiency policies further. Surprisingly, acting on the cost of electricity through increased energy taxation seems to have only a very limited effect; financial disincentives to high energy consumption should be rather included in the retail price of a good to achieve a greater effect for the same economic costs to the consumer. Further suggestions to reduce discount rates include:

- economic gains of energy efficiency investments should be presented as losses from not doing them;
- only one decision for energy efficiency investments should be required and comparisons between different options minimised;
- the economically optimal option should always be the 'default' one with an active opt-out in situations where individuals can chose;
- the expected returns of an energy efficiency investment should be presented before the required investment costs;
- an update of the available information should be required if there is a considerable time-lag between an investment decision and the actual realisation of the investment costs; and
- easing the access to appropriate funds is crucial, especially for financially constrained individuals, but a low acceptance of taking on debt for investments in energy efficiency could hinder such a policy.

In conclusion, both the behavioural side and the financial side need to be carefully respected when evaluating the impact of public policy. There are at least 809 policy measures on energy efficiency within the EU (Filippini et al., 2014; Tanaka, 2011), and only a thorough assessment can yield reliable information on their effectiveness, taking into account findings from literature such as presented here while considering the assumptions and limitations of each evaluation: only the inclusion of critical elements such as the 'pre-bound effect', which led to a 30 % overestimation of the energy consumption of some German dwellings by policy makers (Sunikka-Blank & Galvin, 2012), and the re-bound effect can deliver correct results concerning the impacts on individuals' behaviour as well as the socio-economic consequences of public policy (Galvin, 2014; Schleich et al., 2014).

Furthermore, any economic model and policy assessment needs to take the diversity in discount rates into account. Even if a given technology is profitable on average, there will be some individuals for whom it is not profitable (Jaffe & Stavins, 1994). Evaluating any kind of inter-temporal decision making based on average data necessitates a linear model – non-linear dynamics, which are typical in the world surrounding us, might lead to wrong results when using only average data, because the impact of investment decisions of individuals with lower than average discount rates might not balance out the impact of investment decisions of individuals with higher than average discount rates and vice versa.

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