
How to Support Energy Efficiency – An Experimental Investigation of Individual Preferences

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Abstract

Increasing energy efficiency is a prerequisite for sustainable, renewable energy systems. In spite of large economic potentials, private households remain hesitant to invest in energy efficiency. Governments aim to close this energy-efficiency-gap by committing significant resources to policies and subsidies that incentivize or force private households to invest. In this paper we present a pilot experiment which contributes to existing literature on private energy efficiency investment behavior. We explore the willingness of heterogeneous households to invest in energy efficiency under alternative institutional arrangements and draw conclusions on the efficiency and effectivity of different policy measures to stimulate private households' efficiency investments.

We control for the effects of flat subsidies and forced investments on cooperation in a non-linear public good game with heterogeneous endowments and preferences. We find that in the absence of policies, households behave slightly cooperative and invest more than the profit-maximizing amount independent from their endowments. When grants are offered to low-income households, receiving households cede to cooperate entirely, while remaining households do not change their behavior. We also observe that cost sharing rules determine collective investments and find that progressive financing schemes for subsidies reduce overall investments. Finally, investment obligations below Nash-levels do not alter investment decisions significantly. Due to low case numbers, our results need to be interpreted cautiously. However, the results presented in this paper suggest that the effects of flat subsidies for energy efficien-

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cy investments are limited to the redistribution of endowments and that investment obligations might be used to establish energy efficiency standards without provoking behavioral effects.

1 Introduction

During the last two decades energy efficiency has become a strategic goal of energy policy. Economic literature addressing the broad field of energy efficiency has arrived at three core conclusions (Prindle et al. 2010): *First*, a large technical potential to increase energy efficiency and to curb energy consumption at low cost is identified in all sectors of the economy. *Second*, despite this technical potential the willingness of market participants to invest in energy efficiency measures is rather limited. Different barriers or market failures such as asymmetrical evaluations of cost and benefits are held responsible for the gap between potential and actual investment behavior. *Third*, these barriers account for a broad consensus that policy measures are needed to promote energy efficiency investments. In the face of a multiplicity of political instruments it remains controversial which policies are best suited to achieve efficiency goals: On the one hand, subsidy programmes and information campaigns are used to promote voluntary investments. On the other hand, regulative measures such as efficiency standards for buildings or household appliances are imposed to force firms and households to invest in energy efficiency.

Individual decision making in the field of energy efficiency and the role of efficiency policies have been extensively investigated from a micro-economic perspective. Offering well-designed hypothetical investment projects and using classical survey-based stated preference methods core decision making determinants are identified. Alberini et al. (2013), for instance, find that uncertainty about future energy prices, upfront costs of investments and potential energy savings significantly alter investment behavior. Facing high uncertainty, household owners tend to stall energy efficiency investments altogether. High upfront costs decrease the likelihood for households to invest in energy efficiency, while larger saving potentials have a contrary effect. Comparing up-front costs and savings, households reveal low implicit discount rates. It could also be shown that government subsidies increase the likelihood of households to invest more than a cost decrease of the same magnitude. Such effects of political programs aiming to support energy efficiency investments mark a separate field of research. Here, papers assess the economic feasibility of government programs and stress the importance of free-riding (see for instance Grösche and Vance 2009).

When making assessments of efficiency policies, we believe that there are two additional considerations that need to be made regarding the utility resulting from energy efficiency investments: First, energy efficiency investments have local, private effects as they reduce an investing household's energy expenditures and generate private savings.

At the same time, increases in energy efficiency and the resulting decline in energy consumption save greenhouse gas emissions (rebound effects and the effects of increased comfort are neglected). Hence, energy efficiency investments combine the properties of private goods (private investment costs and expenditure savings) and public goods (environmental protection). Energy efficiency policies thus affect the provision of an *impure public good* (Cornes and Sandler 1996; Kotchen 2005; Chan and Kotchen 2014).

The second consideration concerns the fact that the utility provided by energy efficiency investments depends on highly heterogeneous household characteristics. As energy savings potentials are more substantial in households with high energy consumptions, households might react to energy efficiency policies in accordance to their potential benefits. Also, the access to energy efficiency investments is limited by strongly divergent household incomes. Furthermore, different uses of household objects may lead to differences in preferences even if household parameters such as income and energy demand are identical (Alcott and Greenstone 2012). The role of heterogeneous household parameters is relevant for the *distributional effects* of energy efficiency policies, too: To combat the perceived social imbalance that are the regressive effects of increasing energy prices, specific subsidy programs are designed for low-income households to assist their efforts to invest in energy efficiency measures (Neuhoff et al. 2013; Alberini et al. 2013). However, as such subsidization of energy efficient appliances causes public expenditures, questions of the distribution of these costs within society arise (Chawla and Pollitt 2013; Achtnicht and Madlener 2014). Previous experimental results show that individuals' willingness-to-pay for climate protection is significantly affected by social preferences and attitudes towards the perceived fairness of cost allocation methods (Menges and Traub 2009). It might be argued that questions of perceived justice might also influence the effects of energy efficiency policies.

Both the impure public good character of energy efficiency investments and the distributional effects that result from government programs to increase investments are largely omitted in the empirical literature on energy efficiency investments thus far. Instead, focus is put on "market failures" when making cost-benefit analysis of energy efficiency policies. In this paper we present a pilot experiment conducted with university students in university class rooms¹ which contributes to existing literature on private energy efficiency investment behavior. We explore the willingness of heterogeneous households to invest in energy efficiency under alternative institutional arrangements. We use a non-linear public good game and draw conclusions on the efficiency and effectivity of different policy measures to stimulate private households' efficiency investments.

The paper is organized as follows: In the second section (Sect. 2) we briefly discuss methodological aspects of public good games and their relevance for the examination at hand. We also provide a short review of the literature on public good games with heterogeneity. In the third section (Sect. 3) we will give a brief introduction of our model and the hypotheses drawn from it. The fourth section (Sect. 4) entails a description of

¹ A comprehensive experiment using samples from the general public is scheduled for early 2015.

the experimental design we employ in the pilot experiment. In the fifth section (Sect. 5) we present the results from the pilot study, the conclusions of which are summarized in the (Sect. 6) sixth section.

2 Experiments on the Private Provision of Public Goods: Methodological Aspects

The methodological bases of our experiment are standard public good games as described by Ledyard (1995). The standard experimental design of public good games requires players $i = 1, \dots, N$ to allocate their individual endowments² to private and/or public goods. Both private and public goods offer utility, the difference being that public use of endowments provides utility to all players while private goods generates utility only for the allocating player. Resources committed to one good are not available for other goods, so that players need to decide between private and public utility. Obviously, optimality of decisions is dependent on the utility functions used for both private and public arguments. Isaac und Walker (1988) introduce the marginal per capital return (*MPCR*) as a classification for public good games and as a general indicator for the strategies these games feature. The *MPCR* describes the marginal utility provided by one unit of the public good divided by the marginal cost of contributing that unit to the public good. The marginal cost of provision is described by the forgone private utility that would have been realized had the marginal unit not been contributed to the public good and instead been consumed privately.

In the standard public good experiment *MPCRs* are constant. Typically, in these so-called linear public good games *MPCRs* are smaller than one and greater than $1/N$, implying that the costs of providing a public good exceed the utility the providing individual derives from said provision. In these settings, the Nash-solution that maximizes individual utility is to not contribute to the public good at all. On the other hand, the assumption $MPCR > 1/N$ requires players to commit their entire endowment to the public good in order to maximize collective utility. Usually parameters are chosen in a fashion that the utility achieved by cooperation exceeds the utility obtained by Nash-behavior. This design leads to a strategic problem referred to as free-riding: Since individuals cannot be excluded from the public good and there are no possibilities of reacting to contributions ex-post, collaborative behavior can be exploited. Rational individuals maximize their utility regardless of foreign provisions and thus don't contribute to the public good. In this situation the rational player increases his utility at the expense of the cooperative one(s), who suffer from utility losses.

In spite of these incentives not to provide the public good, the empirical evidence shows that the average player chooses to cooperate at least slightly, contributing bet-

² In this paper the term endowment will be used synonymously with income and wage.

ween 40 and 60 % of his endowment. Many factors alter the degree of cooperation: Communication between players increases contributions significantly, whereas anonymity has the reverse effect. In repeated decisions, contributions decrease over time with a clear tendency towards Nash-behavior in end-rounds. Additionally, cooperation is less common in larger groups. It could also be shown that cooperation depends on the factual value of the *MPCR*. Higher *MPCRs* imply lower costs of contribution and result in higher overall provisions (Sturm and Weimann 2001).

Experimental setups that feature non-constant and usually declining *MPCRs* are referred to as non-linear public good games. These games incorporate *MPCRs* greater than one and below $1/N$ and arrive at different predictions. Here, individuals maximize their personal utility by contributing to the public good until the *MPCR* equals unity. Collective utility, on the other hand, is maximized at provision levels characterized by $MPCR = 1/N$. This constitutes a fundamental difference in predictions between linear and non-linear public good games. In linear public good games equilibria are corner solutions, whereas in non-linear public good games optima are inner solutions.

In recent years, public good experiments have been modified to analyze the effects of heterogeneity between players on the provision of a public good. Heterogeneity can be created between players in multiple ways: Theoretically, all parameters of a payoff-function can be altered between subjects, and even the utility-functions themselves could be different for participants (see Fisher et al. 1995).³ However, a large part of empirical literature focuses on players' endowments to create inequality. This approach is based on the "neutrality theorem" formulated by Warr (1983) and modified by Bergstrom et al. (1986), which claims that the overall contributions to a public good depend on the aggregate endowments supplied to players, but are independent from endowment distributions between players. The theorem postulates that when income transfers lead to income differences between formerly equally-endowed subjects, the beneficiary of the transfer will increase its contributions to the exact degree that the now worse-positioned subject will decrease his.⁴

Many attempts have been made to validate the neutrality theorem with experimental methods in both linear and non-linear environments. In linear settings, the results on the Warr-theorem vary strongly. Cherry et al. (2005), for instance, contradict the Warr-theorem and demonstrate that heterogeneous endowments reduce private and ag-

³ There are even more sources of inequality that are examined with experimental methods. We would like to mention Anderson et al. (2008) for an analysis of the effects of reward heterogeneity and Oxoby and Spraggon (2006), who discuss the importance of income source heterogeneity.

⁴ For completeness, we would like to point out that there are alternative theorems on the role of income heterogeneity for cooperation. Originating from the social sciences, a theory of psychosocial effects predicts cooperation to decline in environments of heterogeneity, independent from its source (see, for instance, Putnam (2000)). In contrast, Bergstrom et al. (1986) assume heterogeneity to stimulate the provision of public goods.

gregate contributions to a public good.⁵ The results presented by Buckley and Croson (2006) also falsify the neutrality theorem and general intuition, reporting that poorer and richer subjects contribute the absolute same amounts at relatively higher (respectively lower) costs. A different result is offered by Hofmeyr et al. (2007), who conclude from a classroom experiment that heterogeneity does not affect the provision level of a public good: In a comparison of provisions between groups with symmetric and asymmetric endowments they find that the amounts players contribute to the public good are constant relative to their endowments. This so called “fair-share-rule” is interpreted as proof of the neutrality-theorem. Keser et al. (2014) follow a slightly different approach and vary the degree of inequality in endowments between treatments. They observe that small income asymmetries result in provision levels that are not significantly different from provisions in symmetric settings. As heterogeneity increases, the “fair share rule” previously suggested by Hofmeyr et al. (2007) emerges. Yet upon reaching a critical level, inequality causes well-endowed players to reduce contributions relative to their endowments, so that the over-all supply of the public good decreases. Consequently, Keser et al. (2014) neither confirm nor reject the Warr-theorem, and instead introduce the intensity of inequality as a conditional variable.

Non-linear public good experiments also yield equivocal results, even though the scope of literature is much smaller. Chan et al. (1996) examine contributions to a public good in groups of three individuals with changing income distributions. Their between-subjects results contradict the neutrality theorem, reporting that less-endowed (“poorer”) subjects tend to over-contribute to the public good relative to predicted equilibria and that “richer” subjects are more likely to under-contribute. In a subsequent experiment, Chan et al. (1999) are able to reproduce this result and extent its robustness to situations with preference heterogeneity. Maurice et al. (2013) show that asymmetric contribution patterns persist whether heterogeneity is unconditioned (predisposed) or caused from income transfers. However, here the observed group provisions are in line with the neutrality theorem and unaffected by income redistribution.

Fung and Au (2014) make an attempt to explain the mixed reports on the effects of endowment heterogeneity. Defining heterogeneity on a more detailed level, they analyze the aforementioned experiments in two categories: The level of inequality (variability of endowments, measure: Gini-coefficient) and the asymmetry of resource distribution (distribution of endowments, measure: skewness). Building on the observation that endowment schemes may inhere the same level of inequality at different levels of skewness and vice versa, level of inequality and its asymmetry are identified as independent variables. The role of both variables for contribution patterns is examined in a linear public

⁵ Aside the Neutrality-theorem, Cherry et al. (2005) also investigate the effects of endowment origin on contributions. Endowments that are earned in prior tasks are treated no different than endowments that are provided unconditionally. Readers interested in the interaction between endowment heterogeneity and origins of endowment are referred to Spraggon and Oxoby (2009) and Kroll et al. (2007).

good game. An important implication is presented in the finding that skewness of endowment distribution significantly alters provision levels: The more symmetric income distributions are, the stronger the tendency for individuals to reduce cooperation is.

All-in-all, there are two conclusions that can be drawn from the experimental evidence on heterogeneity in pure public good experiments. First, the effects of inequality differ widely and seem to vary with methodological approaches such as source of inequality, degree of inequality and distribution of inequality. The choice between linear and non-linear approaches also determines the significance of endowment heterogeneity. Second, individual contribution patterns in heterogeneous settings may to a large extent not be explained by standard economic theory, since players tend to voluntarily trade (parts of their) individual profits for the benefit of the group.

The above discussion centered on pure public goods that are supplied in continuous levels. There is an equally rich literature on the factors influencing the provision of pure public goods in discrete levels, particularly on threshold public good games.⁶ Meanwhile, the experimental literature on the provision of *impure* public goods is far less developed.

Theoretical models on the provision of impure public goods are well established and used to describe, for instance, the demand for impure public goods on so-called green markets (Menges et al. 2005; Chan and Kotchen 2014). Under the assumption that impure public goods describe a joint production of private and public goods, these models show that demand for environmental quality depends on wealth, exogenously given levels of public goods, and the technologies of joint production. Other models depict the effects of income transfers on the provision of impure public goods (Ihori 1991) or discuss the need for inequality in endowments for efficient allocation (Dasgupta 2009). Experiments on impure public goods, however, are rather uncommon. This is because the provision of any impure public good may be regarded as a joint-production of pure and public goods (Kotchen 2005). Since any benefit provided by the private component of the impure public good relates to the also private cost of contribution, ultimately every impure public good game can be reduced to a pure public good game. This explains why existing experiments that feature impure public goods mainly center on questions of provision mechanisms: Engelmann et al. (2012), for instance, address the effects of coexistence of impure and pure public goods on public utility. They simultaneously present probands with different possibilities of contributing to a public good. They show that when there are two coexisting ways to contribute to a public good, namely direct contribution to a public account and indirect contribution via an impure public good, the existence of the impure public good tends to reduce the aggregate provision level of the public good. In an experiment reported by Munro and Valente (2009), probands also face the choice of consuming a private good, a public good and an impure public good. They control

⁶ We refrain from reviewing this strand of literature, yet refer readers interested in the effects of heterogeneity to Rapoport and Suleiman (1993) and van Dijk and Grodzka (1992). A variable that is exclusively relevant in threshold public good games is the so-called provision point mechanism. See, for instance, Rose et al. (2002) and Spencer et al. (2009).

the overall utility provided by the impure public good as a sum of private and public benefits and relate that utility to provision cost. This measure of efficiency is altered between treatments, as is its composition of private and public components. One result of the experiment is that “inefficient impure public goods” with benefits below consumption costs decrease over-all provisions of the public good, although predictions would have suggested neutrality. Shifting the composition of private and public utility of the impure public good, they also find that impure public goods that provide mainly private utility lead to lower aggregate public utility. Meanwhile, if the public component of the impure public good dominates, no significant changes to a baseline-treatment are found.

These considerations on impure public goods as provision mechanisms can be applied to the problem of energy efficiency: The environmental effect of energy efficiency investments may be realized without joint private benefits of energy expenditure savings, for instance via donations. However, the research at hand follows different research questions, trying to assess the role of heterogeneity and/or allocation instruments on provision levels.

We believe a non-linear function is best suited to model the utility derived from energy efficiency investments for two reasons. First, the usage of linear models would require individual profit maximizing investments to be null. In essence, such an approach would ignore existing evidence of economic saving potentials related to energy efficiency investments in private households. Second, the non-linear payoff functions represent non-linear abatement cost curves associated with many environmental problems. Discussing a local environmental Remedial Action Plan in Canada Chan et al. (1999) point out:

All parties have different sizes, different interests, and different abatement cost structures. This leads to payoff structures which are imperfectly known to one another and almost certainly non-linear(...). The key aspects of this field environment are that the agents differ in at least two dimensions (size and cost structure), that they are incompletely informed about each others' *[sic]* payoff structures, that they can and do communicate with each other before making voluntary contributions to a public good, and that the problem is non-linear in the sense that the optimal allocation of resources almost certainly lies in the interior of the choice set. The voluntary contribution mechanism for the provision of public goods seems to be an appropriate model of the field environment. This suggests that the theoretical and empirical literature on the voluntary contribution mechanism should give some insight into the problems faced in the field. In particular, one might ask whether the heterogeneity in the size and payoff structures of the agents will promote or hinder achieving a co-operative outcome. (Chan et al. 1999, p. 5).

3 Model

Modelling the effects of energy efficiency investments we make out three core implications. First, goods and services suitable to increase household energy efficiency are traded on markets. Just like any other marketable good efficiency improvements are sold at a

price that implies opportunity costs of investments in terms of forgone consumption (A). Second, we address the connection between a household's energy efficiency and its energy consumption. An increase in energy efficiency reduces the energy demand with two distinguished results. On the one hand, assuming constant energy prices the reduction of energy consumption leads to financial savings (B). On the other hand, looking at energy supply the decline in energy consumption lessens the amount of resources needed to satisfy customer demand. Considering the environmental effects associated with power generation—for instance greenhouse gas emissions—the enhancement of energy efficiency protects the environment (C). Unlike the opportunity costs and energy expenditure savings, the environmental effect of energy efficiency investments forms an external effect and applies not only to the investing household, but to every household sharing the same environment.

In order to ensure fungibility between those implications, all consequences of investment decisions are quantified in monetary units of a not specified currency. While this approach seems logical in the cases of opportunity costs (A) and energy expenditure savings (B), describing environmental effects of energy savings (C) financially requires a particular framing, which will be discussed later.

The model used in this experiment defines the outcome $\pi(I)$ of energy efficiency investments I as the sum of the implications stated above. The general form of the payoff-function is thus:

$$\pi(I) = A(I) + B(I) + C(I)$$

The mathematical description of the summands A, B and C as a function of the energy efficiency investment I is designed in accordance with the following assumptions:

1. The decision variable I —the amount a household invests in energy efficiency measures—is continuous and equal-or-larger-than zero. A household i is restricted in his decision-making by its income W_i and its given pre-investment energy consumption E_i . The deviation of household income and its energy consumption defines the disposable income D_i which marks the upper limit of household investment possibilities.⁷
2. Opportunity costs A reduce the payoff of the investing household. The marginal cost of investment is linear and directly proportional to the invested amount.
3. The energy expenditure savings B a household realizes with a given investment is limited by its pre-investment energy consumption E , implying that energy efficiency investments cannot reduce the energy consumption below zero. Not investing in energy efficiency does not generate savings. The marginal saving of energy investments is positive yet diminishing.

⁷ The model excludes energy pricing, setting the price of every energy unit consumed to one. Higher energy consumptions thus equal higher energy expenditures. This price remains constant and is independent from over-all consumption respectively demand.

4. The external effect of energy efficiency investments C is a function of the predisposed energy consumption E . The higher the energy consumption, the stronger the external effect. Again the marginal effect of investments on the external effect is positive and diminishing and converges against a multiplier of E . The external effect is negative below a critical investment level and becomes positive for investments exceeding this critical level. The total external effect determining the payoff is the sum of individual environmental effects.

For a number of $i \in \mathbb{N}$ households, the outcome of energy efficiency investment decisions π_i for household i is described by the payoff-function:

$$\pi_i = (W_i - I_i) - E_i * \left(1 - \gamma + \frac{\gamma}{e^{(a*I_i)}}\right) + \sum_{i=1}^n \left(1 - \frac{\beta}{e^{(a*I_i)}}\right) * \frac{E_i}{\varepsilon}$$

The parameter $a \in [0,1]$ is growth-factor of the limited growth-functions used in calculating the energy expenditures and the environmental effects. The parameter $\gamma \in [0,1]$ is used to calibrate the amount of energy expenditure savings a household achieves with a given investment. The product $E_i * \gamma$ also defines the limit value savings converge on. Parameter $\varepsilon > 0$ serves a similar function and is employed to calibrate the external effect of investments. In order to determine the impact of hold-off investments on the external effect parameter $\beta > 1$ is used. β also defines the critical level of household investments $\frac{\ln(\beta)}{a}$, that causes negative external effects to become positive. All parameters are constant and greater-or-equal to zero. Parameters with index i differ between subjects. The calibration used in the pilot experiment is listed in Table 8 in the appendix.

Describing the utility gained from energy efficiency investments with the above model, we leave aside two meaningful aspects of real-life investment decisions. In reality, the financial savings achieved by increases in energy efficiency highly depend on volatile energy prices. Similarly, investment objects and retrofits might require unforeseen maintenance that annuls initial cost estimates and endangers profitability of investments. Consequently, the degree of risk-aversion of decision-makers as well as objective and subjective likelihoods strongly influences the probability for investments to be made (Qiu et al. 2014). Also, even in the absence of risk, economic assessments of investments are determined by time-preferences. Households need to compare future savings with present spending, which requires future benefits to be discounted. Empirical evidence has shown discount rates for energy efficiency investments to be large, with values ranging from 25 to 100 % (Gillingham et al. 2009; Alberini et al. 2013).⁸ Our model excludes risk and intertemporal considerations not because we distrust existing evidence, but to keep complexity to a minimum. We acknowledge the great relevance of both aspects of decision-making, yet as an initial approach to our research questions—the effects of allocation and distribution policy instruments on investment decisions—we consider a

⁸ Questions of discounting and risk-attitude might be interlinked, as the discount factor itself might be subject to risk. See Thompson (1997) for a discussion.

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