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How relevant are free-rider effects for target achievement?

- updated version -

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ABSTRACT

To reach energy savings or greenhouse gas emission targets, energy efficiency measures that are often initiated and subsidised by governments are commonly applied. Results presented in empirical papers support the assumption that measures such as subsidized loans or grants induce the use and diffusion of energy efficient technologies. However, governments have limited budgets and thus try to use their scarce financial means as efficiently as possible: They strive to achieve energy savings goals by least costs. However, many efficiency policies are confronted with moral hazard problems, free riding, rebound effects and others. This paper discusses to what extent free riding is a problem when designing energy efficiency measures. And it debates how relevant it is for achieving the emission target. For this, the paper reviews about 50 evaluation papers addressing moral hazard and free riding problems of energy efficiency measures, compares their findings and contrasts them with different approaches assessing energy savings as well as with the different types of support measures. The results of the literature analysis show that those investors that do free-ride contribute a large share to energy savings. However, those efficiency gains are partially offset by rebound effects. Therefore, free-riding is not a problem with respect to target achievement, but a problem of cost effectiveness, while rebound effects are endangering the energy savings and emission goals. Further, we argue that free-riding is rather independent of the type of policy support, even though it is often related to public expenditures. In contrast, it depends on the ambition level of the measure. Many energy efficiency measures with low public expenditures either entail higher private expenditures or go hand in hand with a lower diffusion of efficiency technologies while increasing public expenditures increases the likelihood of free-riding. Thus, we argue that there is a trade-off between free-riding, public and private expenditures. Finally, free-riding matters with respect to cost effectiveness but not regarding target achievement.

Introduction

Energy End-use Efficiency (2012/27/EU) (EED) of the European Union requires the member states to define and attain an overall target of at least 1.5% annual energy savings between 2014 and 2020 in final energy consumption. This has to be achieved by setting up an energy efficiency obligation (EEO) scheme or alternative policy measures, e.g. energy efficiency programs (EEP). Some common methods and principles for calculating energy savings are outlined in the EED. Measuring and summing up energy savings derived from the EEO and EEP is important to monitor the achievement of the EED's objective. Achieved energy savings are used as a measure of effectiveness of the implemented energy efficiency policy and for efficiency aspects. Thus, the purpose of the evaluation determines what kind of energy savings is needed. Our hypothesis is that the calculated energy savings used to learn about policy efficiency differs from the assessed energy savings used to monitor national target achievement. This paper focuses on this difference.

The starting point of this paper are two statements. The first statement refers to the evaluation objectives: the evaluation objectives of energy efficiency programs and the EED are different. The EED objective accounts for the whole energy savings achieved in a country, the programme objective only for the respective programme (Thomas et al. 2011). Thus, the latter focuses on a system level while the first represents an aggregated result at the national or macro level.

The second statement refers to cost-effectiveness or efficiency, which is considered as one of the core elements of energy efficiency program evaluations affecting policy design and budget allocation (Yushchenko, Patel 2017) when accounting for cost-effectiveness of policies or programs. We argue that the main difference between energy savings in the framework of the EED and energy savings with respect to cost-effectiveness is the free-rider effect[1]. Thus, the aim of this paper is to show that free-riding does not matter when assessing the target achievement but matters for analysing efficiency.

The paper provides first a literature review on free-ridership and energy savings. Then it outlines how additional energy savings are derived from energy consumption. This is followed by discussing theoretically and practically the free-rider problem. The paper closes with a conclusion.

Literature Review

Data base for literature

In the framework of the project EPATEE (https://epatee.eu/main-results) a Knowledge Base is developed. It encompasses theoretical papers such, guidelines on evaluations of energy efficiency measures and methodological papers, and practical evaluation papers and reports describing, discussing and analysing respective energy efficiency measures (EEM). The objective of setting up such a database is to collect and make information available for experience sharing and capacity building, and not to be representative nor exhaustive. Currently, it includes about 180 studies, of which around 50 address free-rider effects in more or less depth and on which our literature review and discussion is based.

First studies addressing free-ridership in this literature database were of more theoretical or methodological nature. With increasing number of methodological studies, practical papers included more and more this topic as well. Figure 1 depicts the evolution of the topic free-riding in evaluation papers over time. About one-fifth of these papers conducted an own assessment of free-riding effects, one fifth referred to free-rider shares from other studies, the remaining papers conducted a qualitative analysis or discussion on free-riding. Most of the paper discussed free-ridership in the context of net energy savings, about one-fifth linked the calculation of net energy savings to policy effectiveness or even cost-effectiveness of energy efficiency support policies. Finally, the free-rider effects mentioned in these reviewed papers vary significantly between studies, i.e. between the types of EEM, sectors and actors.

[1] It is assumed that energy savings of each energy efficiency measure is only counted once, i.e. no double counting occurs.

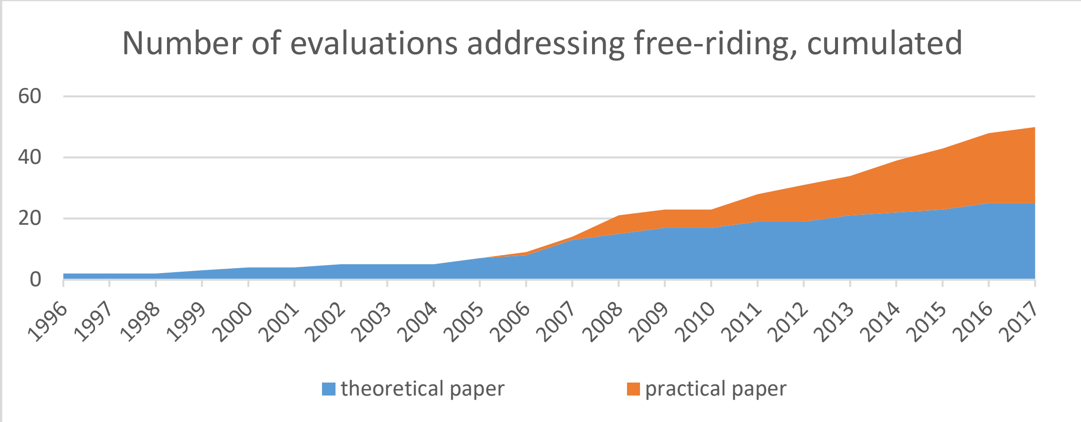

Figure 1. Papers addressing free-rider effects, over time; Source: Studies from EPATEE knowledge base

Free-rider

Malm (1996) is among the first authors who discusses **free-rider** effects in the context of energy efficiency programmes. According to him, free-riders are actors that would have invested into energy efficiency measures (EEM) even in the absence of support programmes. Other authors (Paramonova, Thollander 2016; Vine, Sathaye 1999; Wade, Eyre 2015a) comply with this definition: free-rider are market actors who make use of facilities or support from the intervention but would have taken energy-saving actions anyway. In contrast, Rietbergen et al. (2002) does not explicitly apply the term free-rider effects but discuss it in the context how policies have changed investment behaviour and stimulated energy savings. When assessing energy savings, free-rider effects are relevant as soon as subsidies are involved, not when minimum standards are applied (Nilsson et al. 2008; Nauleau 2014). Similar, Moser et al. (2012), who use dead weight as a synonym to free-rider effects, define free-riding in the context of EEM that would have been implemented without subsidisation (e.g. subsidy). But Vine et al. (2001) subsume free-ridership also for labelling and standard programs as these might affect some purchases. However, as Skumatz (2009) points out, some studies require free-riders to meet four criteria, they should be aware of the EEM before the policy/programme, intend to purchase the EEM before the programme, know where to purchase the EEM and be willing to pay the non-subsidised price.

Moreover, some authors differentiate free-riders. Total, full or pure free-rider would have installed the same EEM at the same time whether or not the program is offered, partial implement only a part of the EEM, deferred free-rider would have installed a less efficient or the same EEM but at a later time (Schiller 2007; Broc et al. 2009; Collins, Curtis 2016). Olsthoorn et al. (2017) distinguish between weak free rider and strong free rider, whereas the first decides to adopt a EEM once they propositioned with an attractive EEM and the later has already decided to adopt an EEM in the near future. The weak free-ridership depends on income, risk and time preferences and environmental identity. In contrast to this, free drivers are persons whose awareness has been raised by hearing about the program (Alberini, Bigano 2015; Vine, Sathaye 1999). With respect to energy efficiency obligations, Moser (2017) applies different terms to address net savings and free-ridership. He defines additionality, i.e. additional EEM as those EEM that would not have been implemented without the respective energy efficiency policy in force. Accordingly, additionality is the opposite or antonym to free-ridership. Further, he states the higher the share of additional measures, the more effective is the policy instrument. Envisaged savings are assumed savings under a given set of policies, accredited savings are derived on the basis of standardized savings metrics, while real savings differ by the additionality principle from accredited savings. Similar, Wade, Eyre (2015b) consider free-ridership as a lack of additionality. This view is supported by Larsen

(2013) who defines additionality exactly as the counterpart of free-riding:"… that energy savings would not have been realised without the obliged party's involvement."

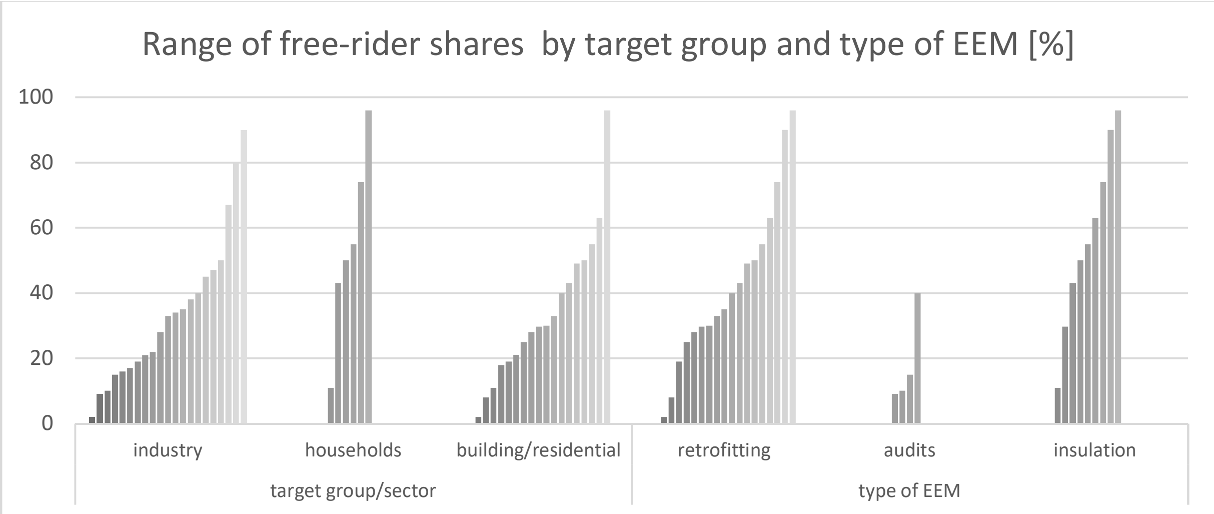

Figure 2. Free-rider shares applied in literature; Source: own composition of data based on studies from EPATEE knowledge base. Note: EEM: energy efficiency measure.

Eichhammer et al. (2008) recommend accounting for free-rider effects if the aim is to evaluate energy savings additional to baseline projections. Wade, Eyre (2015a) point out that free-ridership matters for some methods applied, while it can be ignored with a counterfactual based on control group approach if the propensity to make changes is the same in the participant and control group. Eto et al. (1996) argue that not accounting for free-rider effects increases the effectiveness of policies, but on the other hand it is difficult to single them out. Overall, assessing and accounting for free-riding differs from study to study, some assume free-riders cancel out with other effects, some assume a certain percentage of participants are free-riding, or others assume zero free-ridership (Alberini, Bigano 2015). Further, free-ridership differs by the type of EEMs (Vine, Sathaye 1999) and sectors, and it depends on the socio-professional category, e.g. education, and income (Nauleau 2014). Because it is difficult to account for all the individual aspects at the EEM level with a reasonable amount of effort, as Moser et al. (2012) state, only average effects are taken into account. Figure 2 shows the range of assessed or applied free-rider shares in the reviewed studies. For example, it reveals that in industries the free-rider shares range from almost zero to about 90% because of different EEM measures, different costs, lifecycles, countries, and firms. For households, the shares range between 10% and 96%, for buildings/residential between 2% and 96%. The variation in shares is due to different type of measures, costs, household characteristics, country, year of analysis, methods, programmes, etc.

Andersson et al. (2017) compare in their paper different evaluation studies of energy audit policy programs by reviewing different energy audit policy program evaluations. They point out that some papers do assess free-rider effect by including a question whether the energy audit or the efficiency measure would have been implemented even without the program, while others just apply estimates from other studies. Some studies assess free-rider shares based on questionnaires or surveys (revealed preferences, self-reporting programme influence), other studies base their results on other studies or adjust survey results by expert knowledge. The self-reporting approach is seen as the lowest-cost, most common and accessible way to control for free-ridership, but it also has some weaknesses which might be mitigated by relying on additional data sources such as personal surveys, project and market data or econometric assessment (Schiller 2007). Another approach has been pursued by Grösche et al. (2013) who estimated the free-rider share based on the difference between the willingness to pay and actual total costs of an EEM. Rathbun et al. (2003) have elaborated a flowchart summarizing the steps how to quantify free-ridership through interviews. Finally, Andersson et al. (2017) state that the free-rider effect is important from a cost-effectiveness point of view.

Additionality

The EED obliges the EU countries to set up an energy efficiency obligation scheme or alternative measures to achieve new energy savings of at least 1.5% on an annual basis and the Member States have to publish these obtained savings. Those new savings should be material, i.e. additional to the one obtained by other existing EU requirements, in particular, this refers to the minimum standards set in the EPBD, ESD or EDD (Rosenow et al. 2016). For example, Di Santo et al. (2014) have conducted an assessment which baseline is based on minimum standards. In summary, the ex-ante or ex-post assessments of the national energy savings target rely on planned or implemented policy measures according to EED §7, which energy savings are defined as additional to the minimum standards.

Following Larsen (2013) additionality of an EEM is given, if there are energy savings that are additional to what would have occurred without the energy efficiency intervention. This clearly contrasts with the understanding of the European Commission (2016) which uses existing EU minimum standards to reference additionality (Rosenow et al. 2016). However, in most of the studies, additional energy savings are gross energy savings adjusted by free-rider and spill-over effects, and double counting (e.g. Paramonova, Thollander 2016).

Effectiveness and efficiency

Khan (2006) defines **target achievement** as the extent to which targets that were set for the instruments have been achieved. Schlomann et al. (2017) provide a more general definition: ”... the degree of implementation of the objectives originally defined.” while they relate effectiveness with the causality of an EEM, i.e. to which extent the supported EEM has stimulated the energy savings. In case quantified targets for instruments are lacking, the target achievement or effectiveness cannot be determined. This calls for assessing of energy savings when evaluating effectiveness and efficiency of programmes. Therefore, assessing energy savings is a prerequisite when evaluating effectiveness and efficiency, and thus necessary but not sufficient.

Cost effectiveness is defined as the cost per amount of energy saved, i.e. euros per unit of energy saved (Khan 2006) or of gross savings (Broc et al. 2017). Or more specific, the net present value of the estimated benefits from an EEM compared to the estimated total costs (Schiller 2007) or the net present value of total costs (Paramonova, Thollander 2016). According to Harmelink et al. (2008), cost effectiveness refers to the ratio between energy savings and the amount of money invested to achieve the savings. The costs differ by the perspective: end user, society and government, and the total is compared to energy savings corrected by free-rider effects.

Whereas **effectiveness** of a measure is understood as a different term: Rietbergen et al. (2002) and Khan (2007) refers to the causality or the contribution of an EEM to energy savings target when speaking of effectiveness. Similar, Europe Economics (2016) refers to effectiveness as impacts of policies on energy savings stemming from policies and Broc et al. (2017) define it as a “gross” achievement of the EEM related to its targets. In contrast, they consider the **efficiency** of a policy as costs of the measure in relation to its “net” results. Similar, Moser (2017) defines efficiency as costs per unit saved energy and effectiveness as the achieved, real energy savings, and Schlomann et al. (2017) as “funding to be compared with the results obtained through the funding.”.

There are different perspectives on costs (Khan 2007); costs for society, government or private entities such as companies or households. Calculating cost effectiveness entails assumptions about discount rates and depreciations periods of measures. Yushchenko, Patel (2017) distinguish costs of the EEM into program costs, which include financial incentives, program administration costs of the public and private entities, and cost of program participants, which includes remaining investment costs of households. They also account for lost revenues of utilities from lower demand for energy due to energy savings. According to Harmelink et al. 2008 costs differ by the perspective: end user, society and government. Total costs of the EEM comprises total costs for installation, additional administrative costs of utility and agencies implementing the program. Incremental costs are total costs less the net present value of other changes in costs related to the EEM and the total installed costs of an alternative EEM, that would have been installed in the absence of the program (Eto et al. 1996). Rosenow, Bayer (2017) distinguish between programme, societal, administrative and start-up costs. According to them, programme costs occur for the obliged parties and comprise financial support payments, internal administration and implementation costs of the EEO. Social costs include costs of obliged parties and of participants.

Net energy savings as net impacts

In most studies, the first step of calculations provides as result **gross energy savings** at the level of the EEM. They are commonly defined as the difference in energy consumption when an EEM has been implemented compared to a control group, or a minimum standard, or situation before the implementation of the EEM, e.g. in Eichhammer et al. (2008), Schiller (2007). A **net impact** is seen as the difference between a situation with EEM and one without EEM and the situation without EEM might include autonomous energy efficiency improvements (Khan 2007). However, others call for further adjustments. For example for Broc et al. (2009), energy savings are derived by including multiplier effects, free-rider, and double counting according to the ESD. Many other authors (Fleitner et al. 2012; Schlomann et al. 2015; Paramonova, Thollander 2016; Vine, Sathaye 1999; Thomas et al. 2011; Moser et al. 2012; Broc et al. 2009) call for correction of savings by effects such as free-riding, rebound, spill-over or multiplier effects and double counting to derive net savings. In line with them, Stenqvist, Nilsson (2012) define net impacts as gross savings by a number of correction factors such as free-rider coefficient. In keeping with Khan (2007), many authors agree that free-riding and rebound effects give rise to an overestimate of the real savings achieved from an applied EEM and has to be taken into account when deriving net savings (Thomas et al. 2011; Fleitner et al. 2012; Nilsson et al. 2008). Vine, Sathaye (1999) directly refer to programmes when stating, to calculate more accurately project [program] impacts, evaluations should incorporate free-rider and other spill-over effects in their energy savings calculations.

From energy consumption to additional energy savings

To compare impact of efficiency programs and energy savings across policies, sectors and countries, Andersson et al. (2017) and Voswinkel (2018) conclude that uniform performance standards are needed e.g. data categorization, calculation methods, disclosure of discount rates, lifetimes, as well as basic indicators such as program cost effectiveness and total energy savings on the basis of standardized processes.

We do not oppose Khan (2007), that free-riding brings about an overestimate of the real savings achieved from an applied EEM or has to be taken into account when deriving net savings (Thomas et al. 2011; Fleitner et al. 2012; Nilsson et al. 2008). But we argue that free-riding does not matter when evaluating the EED’s energy savings target. This is because it doesn’t matter how they get to the goal of

1.5% increase in energy savings per year, while it matters when evaluating the effectiveness or efficiency of energy efficiency policies.

Looking at the discussion on literature in the preceding section, one can state that term "additional energy savings" within the meaning of the EED aims at avoiding double counting. The line of arguments is, that its reference to minimum standards that should be taken into account to get "additional" savings means not to include anyway achieved savings through the standards. Therefore, the additionality aspect in the EED is seen as avoiding double counting of energy savings from standards and the respective EEM under investigation in the framework of the EED. Second, this paper defines additionality in the spirit of Moser (2017), and free-riding according to Malm (1996). Subsequently, free-ridership is the lack of additionality as Wade, Eyre (2015b) state.

Because energy savings, which are derived from "EED-eligible" EEM and are evaluated to monitor national targets, should be additional in the sense of being beyond those savings from minimum standards, additional energy savings is not equal to the term "additionality" as understood by most of the authors, but refers to double counting. If however, the objective is not to monitor the national target achievement, but the effectiveness and efficiency of programmes, obligations or other policies to improve policy designs and make programmes more efficient, additionality is given if all minimum standards and other policies inducing savings, rebound effects, spill-overs as well as the free-ridership are taken into account. The difference between the national and the programme level is the purpose of evaluations. Subsequently, the reasoning is when evaluating the EED's energy savings target, free-riding does not matter, while it matters when evaluating the effectiveness or efficiency of energy efficiency policies.

This is illustrated by the example of retrofitting of a family home.

The retrofitting of a single house amounts to about additional investments of 10000 Euro and lead to estimated energy savings of about 30 MWh final or 33 MWh primary energy consumption per annum. The energy consumption is based on insulation values (engineering values). To assess the energy savings, the following steps are necessary (see e.g. Schlomann et al. 2015; Broc et al. 2009; Paramonova, Thollander 2016):

1. Assessment of energy consumption:
   this includes a clear presentation of the type of energy, i.e. primary or final energy consumption. Further, the type of data and sources e.g. primary data or secondary data, should be made transparent, because correction or normalization of data depends on the type of data. For example, energy consumption needs to be normalized, i.e. adjusted by erratic factors such as heating/cooling degree days, occupancy level etc., and macroeconomic factors such as business cycle, structural effects. Moreover, implementing EEM entails changes in consumption behaviour, which is captured by direct metering but not when using sales or statistics.
2. Assessment of gross energy savings:
   there are several approaches to assess energy consumption and energy savings (see Schlomann et al. (2015) for an overview) ranging from direct energy savings based on direct measurements of energy use to modelling of energy consumption based on statistics and stocks. The situation with the implemented EEM is compared to a hypothetical situation without the implementation of EEM. Ideally, the situations differ only by the EEM, all other factors are equal (ceteris paribus). The hypothetical situation is often called baseline or counterfactual (Schlomann et al. 2015). Depending on the calculation method of energy consumption, a before-after comparison, control groups or standards are used. In case there are existing EU standards for the respective building or appliance under evaluation, the minimum standards serve as baseline according to the EED §7. Thus, additional savings in

terms of the EED might even become negative in case minimum standards for new buildings were also applied for retrofit investments of the building stock, e.g. EnEV[2] in Germany.

3. Assessment of net energy savings --> national target achievement and effectiveness:
In this paper, we refine and differentiate the term net energy savings into "net savings" and "additional net savings" The term "net savings" disregard free-riding. But it accounts for changes in consumption behaviour (rebound), for difficulties in delineating effects, e.g. double counting, and assigning spill-overs or further induced effects. In general, gross savings are corrected by factors (Schlomann et al. 2015), such as moral hazard and assignment issues. But when applying metered data, rebound effects are already included in these data, while for modelled energy savings a correction is required. Thus, depending on the type of calculation method and applied baseline, the assessment of energy savings already accounts for these effects. The resulting net savings display actual savings of actors, sectors, and nations, and thus are applied to reveal the national target achievement or the effectiveness of the EEM.
4. Assessment of additional net energy savings --> cost effectiveness and efficiency of policies:
Additional net energy savings are used to emphasis how cost-effective policies and efficient financial support are. Therefore, only those savings of EEM will be taken into account that would not have happened anyway, i.e. that are implemented only because of the support or policy. This additionality is the negative print of the free-rider effect (Wade, Eyre 2015b; Moser 2017). To derive net additional savings, net energy savings are corrected by the free-rider share of EEM.

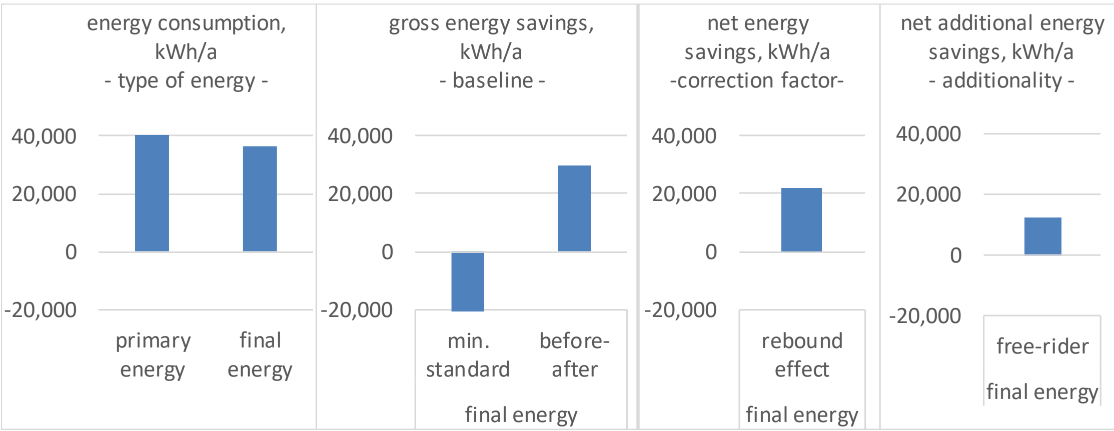

Figure 3. From energy consumption to additional energy savings; Source: own illustration, based on data of Erfahrungsbericht EEWärmeG, 2013

Figure 3 illustrates the four steps described above: the first graph illustrates the differences between primary and final energy consumption of retrofitting in buildings. The second shows the influence of the baseline on the resulting gross savings. There are two baseline examples to which the retrofitting is compared. In before-after case, the before scenario is depicted by the energy consumption of a non-retrofitted building, which is compared to the energy consumption after the retrofitting. In the second case, minimum standards are used as a baseline. Then, the energy consumption of a retrofitted

[2] Minimum standards are set in the regulation (EnEV – Energieeinsparverordnung) in new buildings

building is compared to that of a passive building standard. This second baseline should reflect the consequences of applying the EED with respect to "additional" savings. As the passive building standards are very high, the gross energy savings, and hence the net energy savings after retrofitting are negative. This fact displays how strongly the choice of the baseline affect the results of gross energy savings. The third graph shows the resulting net savings after correcting for the rebound effect (26,7%, see Aydin et al. (2017)) and the fourth depicts additional energy savings when accounting for the free-rider effect (44%, see Nauleau (2014)).

Free-riding and policy efficiency

Similar to Grösche et al. (2013), we consider free-ridership as a problem with respect to efficiency of program interventions, and not to target achievement, while the definition of free-rider as the absence of additionality (Wade, Eyre 2015b) entails also effectiveness aspects. In literature, both terms are used interchangeably. We subsume that policy effectiveness relates to the causality of the policy with respect to implementing EEM and achieving energy savings, while policy efficiency refers to the monetary support or rebate paid to promote the implementation of EEM.

Free-riding

To illustrate the impact of the free-rider effect in economic terms, we chose again the example of retrofitting. To get net energy savings of about 20 MWh per annum (rebound effect is included), an investment of about 10 000 Euro is required. Let's assume that these costs are the same for all households and that the supply and price of insulation is unaffected by demand. Thus, the EEM or the respective net energy savings have a "market price", namely 10 000 Euro. This price is depicted in Figure 5 by the black line. Let's further assume, that households get a varying individual benefit (marginal utility e.g. from better insulation) from implementing this EEM. This corresponds to Grösche, Vance (2008) description of free-riders, whose marginal willingness to pay for an EEM is higher than the total cost of an EEM. The expected benefit of investors is depicted by the blue line (demand) in Figure 4. Given the demand and price, we see that 42 households implement this EEM. Some households (those on the left side of the market equilibrium quantity of 42) were even willing to pay more than the market price. The area above the market price and below the demand line reflects their consumer surplus. Now let's assume that the state would like more households to implement this EEM. Thus, the state decides to give a rebate (2 500 Euro/EEM), which shifts the market price down (black dotted line in Figure 4). As a result, a total of about 60 households implement the EEM. Subsequently, the additionality effect is 18 households in addition, each with EEM leading to a net energy saving of around 20 MWh/a (Figure 3). This example is supported by a study of Alberini, Bigano (2015), which shows that the likelihood of implementing a certain EEM increases with the size of the support (rebate), i.e. the decline in costs for the household.

In our example, the consumer surplus increases in line with the support of the state, i.e. the consumer surplus of those households having implemented the EEM without a support grows and even more households were willing to implement an EEM. The rebate for the 42 households, which would have implemented the EEM anyway, increases the consumer surplus of those 42 households (see Figure 4). Moreover, among the 18 additional households implementing the EEM, only the 18th household pays a price equal to his expected benefit (marginal utility), the others would have paid a higher price. By our definition, this is the additional consumer surplus from implementing additional energy efficiency investment; it is depicted by the shaded triangle in Figure 4. Summarizing, free-ridership shows the consumer surplus gained by households at the expense of the public budget, and that would have implemented the EEM at market prices anyway, while the additionality of the rebate is reflected by the consumer surplus gained by households that would not have implemented the EEM at market prices. Furthermore, the funds for the rebate are 60 times 2 500 Euro, which is reflected by the two rectangles in Figure 4, of which 42 times 2 500 Euro are spent for free-riders, and 18 times 2 500 Euro for additional EEM. The difference between the consumer surplus and the funds spent for the rebate is called deadweight loss (shaded triangle in Figure 4).

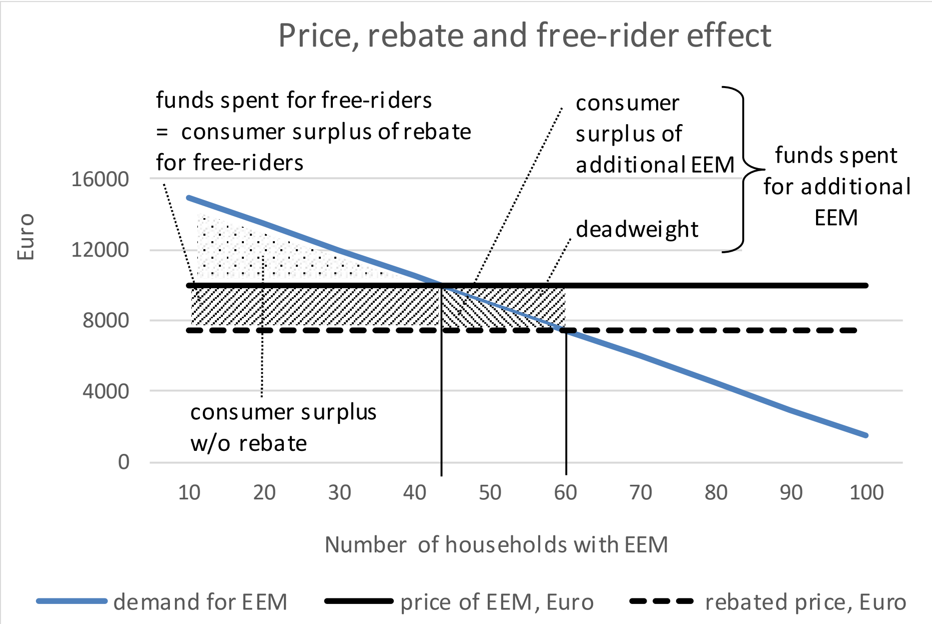

Figure 4. Free-rider effect and additionality; Source: own illustration

Figure 5 illustrates the free-rider effect in case of price elastic and inelastic demand. In case of an elastic demand for the EEM, the free-rider effect is small, and the deadweight loss and additionality large(increase by about 80 households). In contrast, with an inelastic demand, the free-rider effect is large, the deadweight loss and additionality are very small.

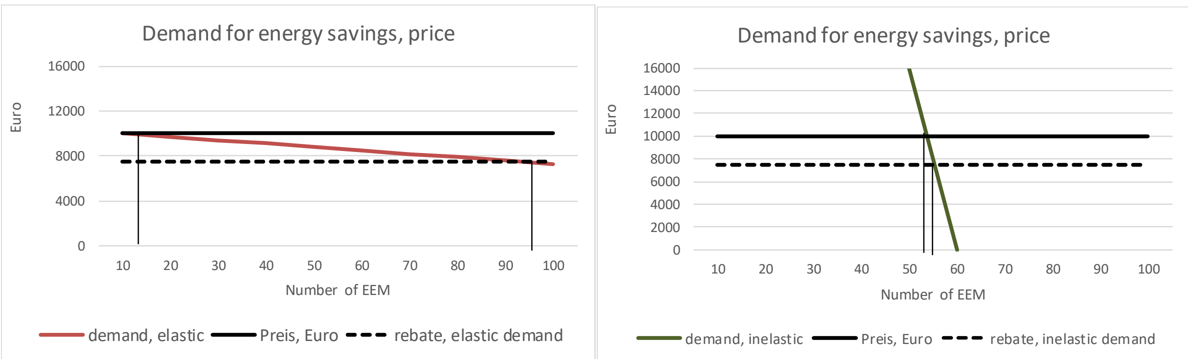

Figure 5. Free-rider effect under inelastic and very elastic demand; Source: own illustration

Policy effectiveness and efficiency

Regarding the effectiveness of the policy support, we conclude that the rebate is effective because it stimulates an additional 18 households to invest in the EEM, but theoretically, only one household is not free-riding. That is, all others would have paid a price above the rebate price. Thus, effectiveness refers to the number of EEM or energy savings stimulated by the policy support.

In contrast, policy efficiency or cost effectiveness accounts for the financial aspect, i.e. the amount spent for the rebate (policy support) to get additional savings, i.e. Euros rebate per kWh energy savings. In the example above, this is a rebate of 60 times 2500 Euros for energy savings of 18 times 20 MWh over 20 years. Applying a discount rate of zero, this amounts to a rebate cost of about 2 ct/kWh. In total, 42 times 2500 Euro are spent for a rebate that resulted in no additional energy savings. Under a highly elastic demand for EEM such as illustrated in Figure 5, only 15 times 2500 Euro for policies are spent and the rebate with about 0.7 ct/kWh were more efficient.

However, policy efficiency in a broader sense includes also program costs (administration) and transaction cost of the state and entity, obliged to implement the policy. Total cost efficiency includes also private costs, i.e. investments into EEM, operation and maintenance costs.

To measure the national target achievement, the actual implemented EEM are relevant, i.e. achieved net energy savings. In line with Andersson et al. (2017), we argue, that free-rider is an efficiency issue, but does not matter for measuring national target achievements. Moreover, the theory-based results present a strong argument to refine the policy design to capture households exactly at their willingness to pay (marginal utility) threshold, but not to stop programmes or supports that address a large array of non-economic barriers.

Conclusion

This paper discusses to what extent free riding is a problem for the objectives of the EED, i.e. national target achievement and for the design of energy efficiency policies. For this, the paper reviews about 50 evaluation papers addressing moral hazard and free riding problems of energy efficiency measures, compares their findings and contrasts them with different approaches assessing energy savings. Results presented in empirical papers support the assumption that measures such as subsidized loans or grants stimulate the use and diffusion of energy efficient technologies by differing degrees. Governments have limited budgets and are supposed to allocate their scarce financial means as efficiently as possible. This means they strive to achieve energy savings goals by least costs. However, many efficiency policies are confronted with free-riding. Even though we analyse free-riding in the context of financial support policies, free-riding is rather independent of the type of policy support, even though it is often related to public expenditures. In contrast, it depends on the ambition level of the measure. For example, investors might fulfil standards, even if minimum standards were not set – thus per definition, they are free-riders.

We agree with the statement of Vine et al. (2001), that an evaluation should account for free-ridership when the focus is estimating savings attributed to the program. Including a predicted free-rider effect in the targets of the energy efficiency obligation as discussed in Ecofys et al. (2006) seem unnecessary, because for target achievement it does not matter whether e.g. a household would have invested into an EEM even without the policy support, only the achieved net energy savings matter - they contribute to the national target. However, if the question is how efficient the EEO works, the additionality question arises and the financial resources spent for the support are compared to the additional savings.

Addressing free-ridership is difficult as it requires detailed data and a sophisticated selection process which heavily relies on the availability of detailed data and information (Lees, Bayer 2016). Our findings are:

- free-ridership differs by the type of EEMs (Vine, Sathaye 1999; Collins, Curtis 2016) and sectors, and depends on the socio-professional categories of households, e.g. education or income (Nauleau 2014). Further, we identified free-rider effect as additional consumer surplus of rebates for households that would have implemented the EEM anyway. Thus, except for a total elastic demand, any rebate entails a free-rider effect, that is, the more inelastic demand for an EEM is the higher is the free-rider effect of rebates, and the more inefficient a measure becomes.

- Correcting for free-riding by using shares derived in other studies is impractical. First, because the specific savings, technology costs and rebates offered as well as the socio-economic background of participants, that influences free riding, differs from program to program. Second, free-ridership is not an issue for national target achievement, but an important issue regarding policy efficiency or cost effectiveness.
- To design efficient support policies, that is to reduce free-riding, some strategies used in marketing might be helpful. For example, firms reduce the consumer surplus by price differentiation (over time, different quantities, product features) or product diversification (quality, availability). Furthermore, price elastic demand for EEM entails larger effectiveness and policy efficiency. Moreover, the larger energy savings, the fewer rebates are needed to make households implement an EEM (Alberini, Bigano 2015).

Finally, many energy efficiency measures with low public expenditures either entail higher private expenditures or go hand in hand with a lower diffusion of efficiency technologies, while increasing public expenditures increases the likelihood of free-riding. Thus, we see a trade-off between free-riding, public and private expenditures and energy savings.

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