Adoption of energy-efficiency measures in SMEs - An empirical analysis based on energy audit data

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Abstract

This paper empiricallyinvestigates the factors driving the adoption of energy-efficiency measures by small and medium-sized enterprises (SMEs). Our analyses are based on cross-sectional data from SMEs whichparticipated in a German energy audit program between2008 and 2010. In general, our findings appear robust to alternative model specifications and are consistent with the theoretical and still scarce empirical literature on barriers to energy efficiency in SMEs. More specifically, high investment costs, which are captured bysubjective and objective proxies, appear to impede the adoption of energy-efficient measures, even if these measures are deemed profitable. Similarly, we find that lack of capital slows the adoption of energy-efficient measures, primarily for larger investments. Hence, investment subsidies or soft loans (for larger investments) may helpaccelerating the diffusion of energy-efficiency measures in SMEs. Other barriers were not found to be statistically significant. Finally, our findings provide evidence that the quality of energy audits affects the adoption of energy-efficiency measures. Hence, effective regulation should involve quality standards for energy audits, templates for audit reports or mandatory monitoring of energy audits.

Keywords: energy efficiency in SMEs; adoption of energy-efficiency measures; barriers to energy efficiency

1. Introduction

Greenhouse gas emissions will have to be substantially reducedto limit the global temperature increase to 2°C. According to IEA (2011), for example, annual global energy-related CO_2 emissions need to be reduced by almost 30% by 2035 compared to 2010.However, under current policies energy-related CO_2 emissions are expected tobe about twice as high in 2035. Improving energy efficiency contributes substantially to emission reductions, especially in the short and medium term. Modeling simulations by the IEA (2011) suggest that under cost-minimization about half of the required cumulative reductions would have to be achieved through improved energy efficiency. In the industry sector, this share is even higher with about 60% (IEA 2011). Such an objective, however, would implydrasticallyacceleratingprogress in energy-efficiency improvements.

While engineering-economic studies (e.g. Granade et al. 2009) typically find substantial cost-saving potentials under current economic conditionsfor many energy-efficiency measures (EEMs), in reality, various "barriers" prevent households and organizations from realizing this potential (e.g. Worrell et al. 2009). Sorrell et al. (2004) classify these barriers into the following broad categories: *imperfect information, hidden costs, risk, access to capital, split incentives and bounded rationality.* Policies to overcome these barriers which target companies include energy management obligations or soft loan programs (Brown 2001; Jochem, Gruber 1990), subsidies for energy audits (Anderson, Newell 2004; Schleich 2004), best practice programs (Neale, Kamp 2009), energy labeling schemes andminimum standards (Garcia et al. 2007). Recent policíes also include combinations such as linking voluntary targets with energy management requirements or energy audits (Jochem, Gruber 2007; Stenqvist, Nilsson 2012; Thollander, Dotzauer 2010). In any case, effective and welfare-improving policy design requires a thorough understanding of the barriers and the differences across sectors and companies (e.g. Allcott, Greenstone 2012; DeCanio, Watkins 1998; Schleich 2009). For example, energy-intensive firms tend to allocate a higher priority to energy-efficiency projects than less energy-intensive firms and larger firms tend to adopt more EEMs than smaller firms (Schleich 2009). In particular, small- and medium sized enterprises (SMEs) consider investments in energy efficiency low priority projects, devote fewer resources to energy management, and exhibit lower adoption rates for EEMs(e.g. Cagno et al. 2010; Gruber, Brand 1991). Thus, barriers related to information, hidden costs and transaction costs are expected to be more pervasive for SMEs, in particular for those with non-energy intensive production processes.

Empirical analyses of barriers to energy efficiency either rely on case studies, and therefore include only a few observations (e.g. de Almeida 1998; O'Malley, Scott 2004;

Rohdin, Thollander 2006), or on surveys involving larger samples. The survey results are often presented as descriptive statistics (e.g. total numbers or shares) of self-assessed barriers (Harris et al. 2000; Thollander, Ottosson 2008). Only some studies apply multivariate methods to analyze the determinants of EEM adoption (e.g. Anderson, Newell 2004; Aramyan et al. 2007; DeCanio, Watkins 1998; Schleich 2009; Schleich, Gruber 2008). However, survey-based analyses typically rely on a rather general description of EEMs and it is often not known whether the EEMs suggested are technically feasible for a particular company. Often, the profitability of the considered EEMs has to be assumed based on data taken from literature rather than empirically assessed at the individual company level.

In this study, we analyze the factors influencing the adoption of EEMs by SMEs, focusing on the impact of barriers. Our empirical analysis is based on novel cross-sectional data obtained from a 2010 survey conducted in order to evaluate the German energy audit program for SMEs. Prior to the survey, all participating companies had been subject to (subsidized) in-depth energy audits. Hence, the information on the cost-effectiveness and other characteristics of the EEMs considered in the survey is specific to the individual firm. The survey also includes a set of questions (items) on barriers to the adoption of EEMs and information on general company characteristics. We employ factor analysis to empirically assess which of the barriers identified in the literature describe the same underlying factor. Grouping the items into these broader barrier factors facilitates the interpretation of the results and contributes to theory building as it allows to better relate the empirical findings to the barriers derived from the theoretical concepts. In our multivariate econometric analysis, these broader barrier factors serve as explanatory variables together with proxies for more objective barriers and for firm characteristics.

In section 2 we review previous empirical work onbarriers to energy efficiency in industry, with a particular focus on SMEs. In section 3 we describe the underlying data set, the variables and the analytical model used. Section 3also includes the factor analysis of the barrier items of the survey questionnaire. Results of the econometric analyses are presented in section4. In section 5 we discuss these results and derive policy implications. The final section concludes.

2. Literature review

Over the last two decades, a substantial body of literature drawing on a variety of concepts including neoclassical economics, institutional economics, behavioral economics, psychology, sociology, and management theory has analyzed why companies and individuals fail to adopt cost-efficient EEMs. Thedifference between the cost-efficientenergy saving potential and the observed adoption of EEMs has been termed the “energy-efficiency gap” (Jaffe, Stavins 1994). The energy-efficiency gap is the rationale for policy intervention to correct investment inefficiencies in addition to policy interventions to correct negative environmental externalities associated with energy use (Allcott, Greenstone 2012; Brown 2001).

For detailed discussions of different types of barriers and classifications, we refer to Brown (2001), Jaffe and Stavins(1994), Sathaye et al. (2001), Sorrell et al. (2004), or Sorrell et al. (2011).We review the empirical work on barriers to energy efficiency in the industry sector, distinguishing between case studies and surveys, and highlighting the studies which involveenergy audit programs.A large share of recent empirical studies (Rohdin et al. 2007; Schleich 2009; Schleich, Gruber 2008; Sorrell 2004; Thollander et al. 2007; Thollander, Ottosson 2008; Trianni, Cagno 2012)relies to some extenton the barrier taxonomy developed by Sorrell et al. (2004). Based on concepts taken from neoclassical economics, institutional economics and behavioral economics Sorrell et al. (2004)develop a taxonomy consisting of the following six broad categories of barriers:

- *Imperfect information*, which includes transaction costs (e.g. search costs) for identifying the energy consumption of products and services
- *Hidden costs*, which include the overhead costs for management, the transaction costs associated with gathering, analyzing and applying information, the costs associated with disruptions to production, or with staff replacement and training
- *Risk*, which captures the technical risks of energy-efficient technologies as well as the financial risks associated with irreversible investments and the uncertainty about the returns of EEMs (e.g. because future energy prices are uncertain)
- *Access to capital*, which includes lack of external and internal funds for energy-efficiency investments. In the case of external funds, the costs to assess the risks associated with the investor (e.g. small EEMs)or the technology might be too high.Internal funds may be inhibited by internal capital budgeting procedures, investment appraisal rules, orthe short-term incentives of energy management staff
- *Split incentives,* which imply that the investor in EEMs cannot fully appropriate the benefits (e.g. landlord-tenant or user-investor problem)

- *Bounded rationality*, which means that constraints on time, attention, and the ability to process information preventindividualsfrom making“rational” decisions in complex decision problems. Rather than optimizing, they use heuristics and rules of thumb to decide on investments in EEMs.

Clearly, as pointed out by Sorrell et al. (2004) these barriers may overlap, co-exist and interact, and a phenomenon may fall under more than one barrier category. When interpreting the findings from surveys conducted after an energy audit has been carried out(e.g. Anderson, Newell 2004; Harris et al. 2000; Thollander et al. 2007),it must be taken into account that the audit may have reduced or eliminated some barriers, such as *lack of information* and *lack of staff* (e.g. Schleich 2004).

Case studies

Case studies are typically carried out for a few companies, and provide a better understanding of complex decision-making processes and structures within organizations. Theory-guided or explorative in-depthinterviews are carried out, transcribed and analyzed to identify the relevant causal mechanisms (Yin 1994) leading to the observed outcomes. In this sense, the findings of case studies may be generalized in an analytical rather than a statistical sense. In the realm of energy efficiency, the case study of the French electric motor market by de Almeida(1998) finds that*split incentives* (or *investor-userdilemma*) in particular impede the diffusion of high efficiency motors: Most motors are bought by original equipment manufacturers who will not be paying the final electricity bill for their use.In addition, bounded rationality(e.g. Simon 1959; Simon 1979)is often observed in firms’ decisions to replace broken motors. They oftenuseroutines like simply buying the same type of motor again, without searching for more efficient alternatives.Ostertag(2003) derives a similar finding for the German electric motor market, but also points outthe role of *information deficits* and *transaction costs*. In a case study of the Irish mechanical engineering industry, O’Malley and Scott(2004) conclude that *access to capital* is the most pervasive barrier. Although firms generally had good access to external funds, EEMs were givena *lower priority* than other projects. The *low priority* might result from the fact that energy expenditures typically account for only about 1% of the total turnover in the mechanical engineering sector. In contrast, in a case study of Swedish non-energy-intensive manufacturing companies by Rohdin and Thollander(2006), *access to capital* was not found to be a major barrier to energy efficiency. Instead, *cost of production disruption/hassle/inconvenience,lack of time* and *other priorities* are ranked highest.Cooremans(2011; 2012) conducted interviews with managers in electricity-intensive firms in Switzerlandand found that financial factors are less important for a firm’s adoption decision than strategic factors. Consequently, in order to increase the adoption rates of EEMs, their strategic value would have to be emphasized. Cooremans(2011) also notes that most companies use payback time as an investment decision criterion. However, the payback time may systematically influence investment decisions against adopting EEMs. In particular, EEMs are often characterized by longlifetimes with benefits accruing in the longer term, but the payback time does not account for differences in the time path of costs and benefits across projects and also ignores differences in lifetimes. However, because of bounded rationality, payback time may be appliedas a rule of thumb.

Surveys

Studies basedon surveys may be distinguishedby the type of analysis. Survey results are either presented as descriptive statistics of self-assessedbarriers,or are derived from multivariate (or bivariate) econometric analyses.

Barrier variables in surveys are oftentaken from subjective judgments by the respondents. One disadvantage of using such self-assessments is that interviewees may adjust their responses to justify their own actions with regard to the adoption of EEMs. Further, Gruber and Brand (1991) for example show that small firms tend to underestimate the cost-efficient potential to improve energy efficiency because they misjudge EEMs available to their firms.Barrier variables may also be constructed from objective information such as whether there is sub-metering of energy consumption, whether buildings are rented, or whether there is an energy management system in place. In a few cases, actual data on profitability or payback time is also available. Descriptive analyses typically report frequencies or shares of particular barriers, or "average" responses based on ordinal assessment such asLikertscales. In econometric analyses, an indicator of observed or reported adoption behavior is regressed on a set of explanatory variables including proxies of barriers as well as other control variables such as organizational size or energy costs. While surveys allow for a generalization of findings in a statistical sense, there are some caveats. For example, results based on descriptive analyses may not hold in a multivariate setting, where correlations across all explanatory variables are taken into account to estimatethe impact of a particular variable on the dependent variable. Further, correlations do not imply a causal relationship. And more generally, it is challenging to find adequate proxies forbarriers such as bounded rationality.

In a survey among UK breweries by Sorrell(2004), *technology inappropriate at this site* was ranked as the most important barrier, followed by *other priorities for capital investment* and *lack of time/other priorities*. For the Swedish pulp and paper industry (Thollander, Ottosson 2008) and foundry industry (Rohdin et al. 2007) descriptive statistics suggest that *technical risk of production disruption* counts as one of the most important barriers to energy efficiency investments.*Lack of capital* is perceived as more important in the foundry than in the pulp and paper industry. For less energy-intensive SMEs in the Swedish manufacturing sector which participated in an audit program,Thollander et al. (2007) find *lack of time* and *low priority for energy efficiency* to be the main barriers. Internal allocation of capital to EEMs in *competition withother investment projects* and the lack of*access to capital* are ranked second and third. In contrast, based on a survey among Australian firms participating in an audit program,Harris et al.(2000) conclude that *lack of capital* and *lack of time/staff* are among the least important barriers. Instead, *payback time too long* and *rate of return too low* were the two most frequently given reasons for non-adoption of EEMs. To some extent, these differences may be explained by the fact that the firms participating in the Australian program are on averagefour times larger than those in the Swedish program (measured by the average number of employees) and hence less likely to face barriers like lack of staff or knowledge, for example. A survey among SMEs in the Italian manufacturing sector during an energy audit revealed a *lack of capital* as the single most important barrier as perceived by the respondents (Trianni, Cagno 2012). This barrier is likely to be amplified by the current financial crisis, which also makes it difficult to compare the findings with those from earlier studies difficult. *Lack of information about energy consumption and EEMs*is ranked as the second most relevant barrier. Finally, in an early survey among German SMEs, which also included in-depth telephone interviews, Gruber and Brand (1991) find that information on available EEMs and support programs is positivelycorrelated with company size.

Anderson and Newell (2004) rely on a large panel of around 40,000 EEMs recommended in more than 9,000 manufacturing plants participating in an energy audit program administered by the US Department of Energy’s Industrial Assessment Centers (US IAC). Anderson and Newell (2004) present descriptive statistics for self-assessed barriers as well as findings from multivariate regression analyses involving objective barriers. Of the more than20 possible reasons given for not adopting proposed projects, *initial expenditures are too high* was mentioned the most (7.1%) followed by *lack staff for implementation* (6.8%) and *cash flow prevents implementation* (6.7%).

In their multivariate regression analysis, Anderson and Newell (2004) control for differences across EEMs and find that *payback time*, as well as the *projectcost of the suggested EEMs* negatively affect the adoption rate of EEMs.Muthulingam et al. (2011) extend the analysis of Anderson and Newell by including behavioral factors from the domain of bounded rationality into their multivariate regression of the same US data set considering about 89,000 EEMs recommended by the auditors. They find that the order of EEM recommendations in the audit reportaffects adoption rates, which fall from above 50% for the first recommendations to around 40% for the last ones.Muthulingam et al. (2011)also conclude that the “attractiveness” of the first measure implemented by a firm influences the likelihood to adopt subsequent measures. Further, by classifying of EEMs into two groups- one requiring high managerial attention and one requiring low attention - they observe that the adoption rate is significantly lower for the former group. The impeding effect on the adoption rate lies in the same order of magnitude as an increase of the investment cost from $ 18,000 to $ 353,000.

DeCanio and Watkins (1998) econometrically analyze survey responses of the corporate executives of firms participating in the voluntary US Green Lights program. Accordingly, participation in the program is mainly driven by firm-specific factors reflecting complex corporate decision-making rather than conventional investment criteria. Based on data from Dutch horticultural firms,Aramyan et al.(2007) find that the adoption of EEMs increases with *farm size, family size*, *solvency*, *modernity of machinery and* if the farm owner has a *successor*. Their set of explanatory variables, however, did not include investment criteria.Diederen et al. (2003)also focus on the Dutch horticultural sector and find that uncertainty about future energy prices increases the hurdle rates and lowers the adoption rate.Thus, as implied by real options theory, it may be best to postpone irreversible investments in energy efficiency if future economic conditions are uncertain (Hassett, Metcalf 1993). The bivariate correlation analysis by Trianni and Cagno(2012), which highlights problems affecting SMEs (“operational” barriers), reveals that the barriers *lack of time* and *lack of internal capital* are morepronounced insmallerfirms (< 100 employees) than in larger firms (100 to 250 employees).As do Trianni and Cagno (2012), various econometric analyses of barriers(de Groot et al. 2001; Sardianou 2008; Schleich 2009; Velthuijsen 1993)also account for differences across industry sectors and highlight the importance of considering firm-specific factors. De Groot et al. (2001) find that the adoption of EEMs is mainly driven by profitability, and that the most important barriers are o*ther, financially more attractive investment opportunities* as well as *incomplete depreciation of the existing capital stock*. Schleich (2009) Schleich and Gruber (2008)and Schleich (2004)focus on the German servicessectorandsmallbusinesses. Findings by Schleich (2009) imply that *lack of information about energy consumption patterns, lack of information about energy-efficiency measures*, *lack of time to analyze potentials for energy efficiency*, *priority setting within organizations*, and *split-incentives* are all relevant barriers, but barriers vary significantly across sub-sectors. Results from individual regressions for 19 sub-sectors in Schleich and Gruber (2008) suggest that *lack of information about energy consumption patterns* and *split incentives* are the most frequent barriers. According to Schleich (2004) most barriers are more pronounced in less energy-intensive firms as well as in smaller firms. His findings further suggest that energy audits help to reduce most of the barriers, but audits conducted by engineers tend to be more effective than audits conducted by utilities or industry sector organizations. This indicates that the *quality of the audit* also affects barriers and hence the adoption rate of EEMs.

An early econometric assessment of barriers in the Dutch industry by Velthuijsen(1993) indicates that the price elasticity of firms' energy demand might be influenced by firm characteristics and the importanceof perceived barriers. These barriers are *limited access to capital, lack of knowledge about EEMs, lack of relevance* (in terms of energy bill), *lack of strategic importance* (i.e. not core business), and *stranded investments* (i.e. capital costs of the technology in place had not yet been recovered). By extending the above analysis to the Dutch, Slovak and Czech manufacturing sectorsVelthuijsen(1995)assessed the investment behavior in manufacturing. He identifies *lacking financial resources* as a major barrier and *favorable market conditions (such as competition), a short payback time* and *low risk* as the main incentives for the adoption of EEMs.In her econometric analysis of the Greek industry,Sardianou(2008)points outthat the affiliation to economic sector and firm characteristics need to be taken into account for policy design as they affect the intensity of barriers.

To sum up, the findings from case study as well as survey-based analyses imply that the corporate adoption of EEMs depends on a variety of interdependent factors including specificbarriers, the characteristics of the firm and the EEM, as well as broader contextual factors like market structure or the accessibility of external capital. Table 1 summarizes the main findings of our literature review.

Comparing findings across studies is problematic since apart from applying different methodologies, the studies differ by country, time, sector, technologies, or barriers considered (types, objective vs. self-assessed). Nevertheless, many of the empirical literature finds that SMEs tend to face more barriers to adopting EEMs than larger companies. The most prevalent barriers for SMEs appear to be lack of capital, and for energy-intensive SMEs, also the technical risk of production interruption. In comparison, adopting EEMs in less energy-intensive SMEs is hampered in particular by lack of information and lack of staff time. These latter barriers couldeffectively be overcome by energy audits.

Table 1: Overview of empirical studies addressing the role of barriers foradoptingEEMs

Study	Region	Sector/market	Sample size (No. firms)	Prior energy audit?	Main barriers and findings
Case studies					
(de Almeida 1998)	France	Electric motor market	n.a.	No	Split incentives resulting from structure of motor market and bounded rationality in motor replacement decisions.
(Ostertag 2003)	Germany	Electric motor market	~10	No	Split incentives resulting from structure of motor market, lack of information and transaction costs.
(O'Malley, Scott 2004)	Ireland	Mechanical engineering industry	7	No	Low priority of EEMs compared to other investment projects.
(Rohdin, Thollander 2006)	Sweden	Non-energy-intensive manufacturing	8	Yes	Cost of production disruption/hassle/inconvenience, lack of time and low priority for EEM investment.
(Cooremans 2012)	Switzerland	Electricity-intensive firms	35	No	Lack of strategic dimension; financial factors are less important.
Surveys – descriptive analyses					
(Gruber, Brand 1991)	Germany	SMEs	500	No	Lack of information and low priority for EEM investment. Lack of information is more prevalent in smaller firms.
(Harris et al. 2000)	Australia	All sectors	100	Yes	Required payback time and rate of return.
(Sorrell 2004)	UK	Breweries	53	No	Inappropriate technology,low priority for EEM investmentand lack of time.
(Thollander et al. 2007)	Sweden	Non-energy-intensive manufacturing SMEs	47	Yes	Lack of time, low priority of energy,internalallocation of capital and lack of access to external capital.
(Rohdin et al. 2007)	Sweden	Foundry industry	28	No	Lack of access to capitaland technical risks.
(Thollander, Ottosson 2008)	Sweden	Pulp and paper industry	40	No	Technical risks andcosts from disruption/hassle/inconvenience.
Surveys – econometric analyses					
(Velthuijsen 1993)	Netherlands	Horticulture, various industry and tertiarysectors	70	No	Energy price elasticity interacts with firm characteristics and the intensity of perceived barriers such as limited access to capital or lack of knowledge.
(Velthuijsen 1995)	Netherlands, Slovak Republic, Czech Republic	Various manufacturing sectors	313 (NL), 40 to 55 (SK), ~40 (CZ)	No	Lack of access to capital, high risk, long payback time, unfavorable market conditions
(DeCanio, Watkins 1998)	USA	All sectors	> 1,000	Yes	Program participation is mainly driven by firm-specific factors rather than con-

					ventional investment criteria.
(de Groot et al. 2001)	Netherlands	Nine industry sectors	135	No	Low priority of EEMs compared to other investment projects, stranded investments.
(Diederen et al. 2003)	Netherlands	Horticulture (greenhouses)	603	No	Uncertainty about future energy prices slows down adoption (real option value concept).
(Anderson, Newell 2004)	USA	Manufacturing SMEs	>9,000	Yes	Required payback period, projected costs / initial expenditures, lack of staff and liquidity constraints.
(Schleich 2004)	Germany	Services and small industry	> 2,000	Yes	Most barriers are more pronounced in less energy-intensive firms as well as in smaller firms. Energy audits helpreducing most of the barriers
(Aramyan et al. 2007)	Netherlands	Horticulture	397	No	Adoption increases with farm size, family size, solvency, modernity of machinery and if the farm owner has a successor.
(Sardianou 2008)	Greece	Industrial sector	50	No	Intensity of barriers interacts with firm characteristics and the affiliation to an industrial sector.
(Schleich, Gruber 2008)	Germany	Services and small industry	57 to 291 per sector	No	Lack of information about energy consumption patterns and split incentives
(Schleich 2009)	Germany	Services and small industry	> 2,000	No	Lack of information about energy consumption patterns, lack of information about energy efficiency measures, lack of time to analyze potentials, and priority setting
(Muthulingam et al. 2011)	USA	Manufacturing SMEs	>9,000	Yes	Confirm findings of Anderson and Newell (2004); adoption affected by the order of recommendationand the managerial attention required for implementation.
(Kostka et al. 2011)	China	SMEs	479	No	Lack of information.
(Trianni, Cagno 2012)	Italy	Manufacturing SMEs	128	Yes	Lack of access to capital. Lack of time and lack of internal capital are more pronounced in smaller firms.

3. Choice of barriers, data and model used

3.1 Empirical representation of barriers used for the model

Our descriptive and econometric analyses, which will be presented in the subsequent sections, capture most of the relevant factors for the adoption of EEMs identified in the literature.A list of factors was derived from previous studies using surveys (Anderson, Newell 2004; Sorrell et al. 2004; Thollander, Ottosson 2008), adapted to the particular situation of SMEs,and extended based on the experiences from past evaluation studies and audit program operators. In total we consider 18 barriers. Our econometric analyses further include control variables reflecting firm size, energy costs, and organizational factors like decision-making criteria and energy management activity, which may also affect the adoption of EEMs.Our econometric analysis distinguishesself-assessed barriers and objective barriers. The former are based on the self-assessment of survey respondents, while the latter represent objectively measurable information.

3.2 Description of the data

The German energy audit program titled “SonderfondsEnergieeffiezienz in KMU” was established in 2008 and provides grants for on-site energy audits in SMEs (< 250 employees).Besides Germany, many countries have also established energy audit programs geared towards SMEs, including Australia, Canada, Japan, the US and most European countries(Price, Lu 2011). As the US IAC program (Anderson, Newell 2004) for example, the “Sonderfonds” is also a stand-alone audit program, i.e. it is not integrated into broader energy efficiency programs involving, for example, voluntary agreements or energy management obligations. While the US program, which was established in 1976, is limited to firms from the manufacturing sector (< 500 employees), the “Sonderfonds” also addresses non-manufacturing sectors such as services. Thus, in the German program a higher share of the recommended EEMs than in the US programis related to buildings rather than to industrial equipment and production processes. Under the “Sonderfonds” the energy audit is carried out by professional engineers and consists of two components. An initial onsite audit provides a rough indication about potential cost-efficient EEMs focusing on measures that are typically available in most firms. In a more detailed analysis, more complex site-specific EEMs are explored. While the audits can be conducted sequentially, firms can also choose to use either the initial or the detailed audit separately. Depending on whether an initial or detailed audit is conducted, the audits take two or more days and result in a list of recommended EEMs deemed to be profitable for the firm based on engineering-economic analyses.Up to 80% of the costs for the audits are paid by the program. The costs for the implementation of the EEMs may be financed by soft loans, which is the second pillar of the “Sonderfonds”. The soft loan program is also available to firms which did not undergo an energy audit. For comparison, US program includes free of charge energy audits offered by teams of engineering students and faculty, but it does not include a financing mechanism. The energy savings achieved via energy audit per firm are about ten times higher in the US program, while the number of audits conducted per month is lower than in the German program.A more detailed discussion of the German audit program may be found in Fleiter et al. (2012).

Our analysis is based on a survey conducted in July 2010 via an online questionnaire sent out to all 4,434 participants in the “Sonderfonds” audit programfor which an Email address was available. The main purpose of the survey was to evaluate the impact and the processes of the program..About 20% logged into the internet portal which hosted the survey and 542 (i.e. 12%) completed the questionnaire but did not necessarily respond to all questions.The length of the survey was a major barrier to completion.Two aspects required a rather long survey. First, the survey was also used for a detailed program evaluation including all its processes. Second, the detailed characteristics of the EEMs recommended by the audit had to be entered for an impact assessment.In total, the survey contained 51 questions on firm characteristics (sector, number of employees, energy consumption, energy cost share, energy management system), on the program application process, on the audit process and quality, on the adoption of EEMs after the audit and on reasons for not adopting recommended EEMs. Figure 1 shows the distributionof adopted and non-adopted EEMsacross the categoriesof end-uses after the audits had been conducted.For example, 32% of the non-adopted measures were in the category building insulation and 24% in the category heating and hot water.Most adopted EEMs address building related end-uses and particularly heating and hot water equipment. Arguably, some ofthe adopted EEMs may have been implemented even without the audit.In contrast, building insulation is the mode for non-adopted measures. In general, the majority of recommended EEMs address ancillary processesrather than the core-production processes.

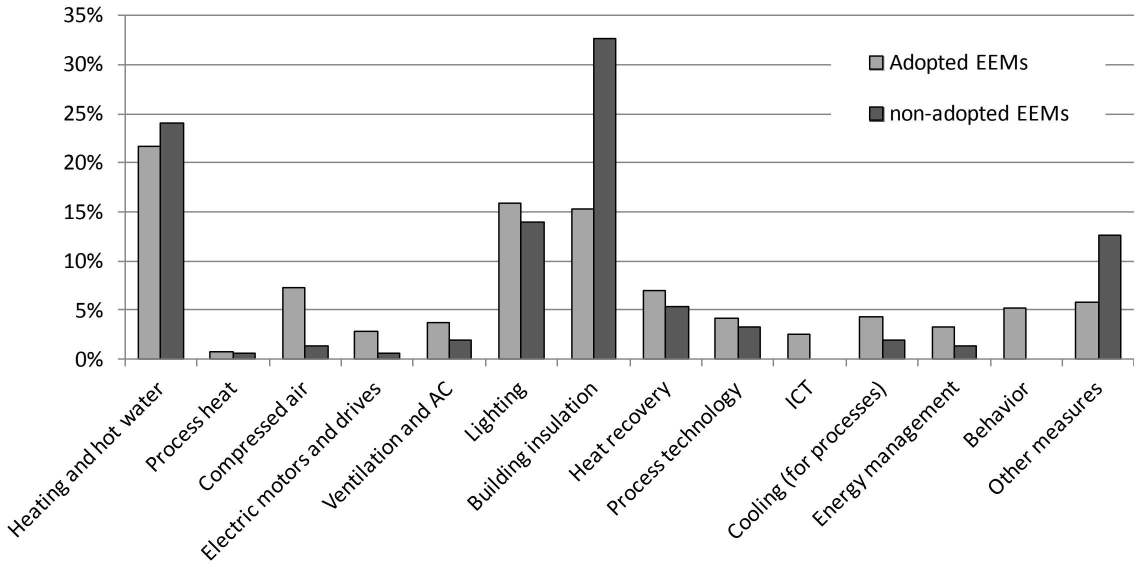

Figure 1: Distributionof adopted and non-adopted EEMs across end-use classes as fractions of the sum of adopted and non-adopted EEMs (n=779)

For EEMs which were recommended by the audit but not adopted by the company, survey participants were asked to assess the reasons for non-adoption measured on a 4-point Likert scale ranging from “not relevant” to “very important”. Thelist of 15 reasons (items)included in the survey isshown in Figure 2.The length of the survey, however, did not allow EEM-specific answers to be elicited. Instead, the answers relate to all non-adopted EEMs (i.e. similar to Schleich and Gruber (2008) and Schleich (2009)). Likewise, the limited length of the survey did not allow the inclusion ofan exhaustive list of all the possible barriers to energy efficiency identified in the literature. For methodological reasons, the survey did not include questions related to *lack of information*about energy efficiency potentials because it targeted specific EEMs identified in the audit. Hence, respondents can be assumed to be well informed about EEMs. Also, barriers like *split incentives embodied in the market structure* (observed in two case studies on electric motors) are difficult to capture in a survey. In generalthe items in Figure 2reflect most of the barriers to energy efficiency identified in the literature.

Figure 2 suggests that the three most important self-assessed barriers to the adoption of EEMs in the sample aretoo high investment costs, low priority of EEMs and lack of profitability. Since most of the recommended EEMsare related to ancillary processes, it is not surprising that barriers related to *technical risks*appear to be unimportant on average.

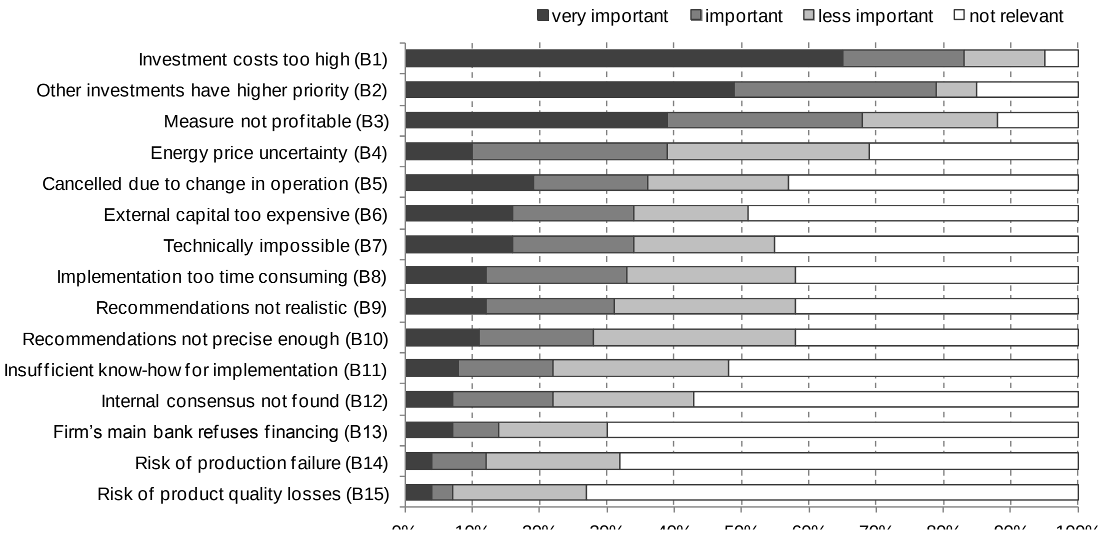

Figure 2: Self-assessed reasons for not adoptingrecommended EEMs(n=160)

The questionnaire also contains eight questions (items) about thefirms’ satisfaction with the audit quality, such as the report, the explanations or the auditor’s competence.Figure 3 suggests that firms were generally satisfied with the audit quality.

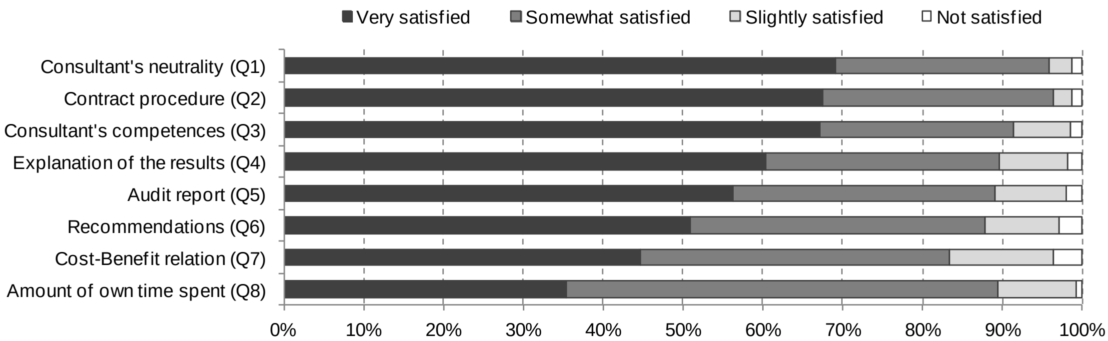

Figure 3: Respondents’ satisfaction with different aspects of audit quality (n=456)

3.3 Factor analysis

To facilitate theinterpretation of the results and toreduce the number of explanatory variables for the subsequent econometric analysis, we apply exploratory factor analysis to group the 15 items ofFigure 2 into underlying barrier factors.[1]Similarly, the eight items in Figure 3 are grouped into quality factors.We employ the principal component

1 For an overview of factor analyses see Fabrigar et al. (1999).

factor method for factor extraction.[2] Based on the Kaiser criterion and the Scree test(see for example Costello, Osborne 2005; Fabrigar et al. 1999) we retain the same number of factors: five barrier factors and one audit quality factor. Table 5 shows the results of the 15 barrier items based on the 138 observationswith a complete set of responses to the items in figure1 and figure 2. Accordingly, the five barrier factors account for 64.7% and the audit quality factor accounts for 66.1% of all variances, respectively.

[2] The Bartlett's test of sphericity $\chi^2(105) = 654$, $p<0.001$ and the Kaiser-Meyer-Olkin measure of 0.71 indicate that the principal component factor method is suitable.

Table 2 provides the loadings of rotated factors using the VARIMAX rotation.Most of the factors comprise a relatively homogenous group of observed variables, such as*lack of capital*, *technical risk*and*low profitability*. Only thefactors*transaction costs* and *low priority and uncertainty* comprise a wider set of barriers. Higher factor loadings imply a stronger effect of the variable on the underlying factor. The values for Cronbach's*α* indicate that most factors are reliable. For the factor LOWPROFIT, however,the value of Cronbach's*α* is well below 0.6, which casts doubts onthe internal consistency of the items.

Table 2: Results of factor analysis for variables of self-reported barriers

Factors and items	Factor loading	Cronbach's α
Lack of capital (LACKCAPITALF)		0.69
External capital too expensive (B6)	0.871	
Firm's main bank refuses financing (B13)	0.788	
Low profitability (LOWPROFIT)		0.38
EEM not profitable (*lackprofit*) (B3)	0.815	
Investment costs too high (*highinvest*) (B1)	0.663	
Transaction costs (TRACOSTF)		0.77
Recommendation not realistic (B9)	0.799	
Recommendation not precise enough (B10)	0.747	
Implementation too time-consuming (B8)	0.619	
Insufficient know-how for implementation (B11)	0.632	
Technically infeasible (B7)	0.437	
Technical risk (TECHRISKF)		0.92
Risk of production failure (B14)	0.908	
Risk of product quality losses (B15)	0.899	
Low priority and uncertainty (PRIORITYF)		0.62
Cancelled due to change in operation (B5)	0.795	
Energy price uncertainty (B4)	0.665	
Other investments have higher priority (B2)	0.647	
Internal consensus not found (B12)	0.486	
Audit quality (AUDITQUALF)		0.92
Explanation of the results (Q4)	0.89	
Consultant's competence (Q3)	0.88	
Audit report (Q5)	0.87	
Recommendation (Q6)	0.85	
Consultant's neutrality (Q1)	0.82	
Contract procedure (Q2)	0.80	
Cost/benefit relation (Q7)	0.78	
Amount of own time spent (Q8)	0.54	

We nowbriefly relate the outcome ofthe factor analysis to the literature. The barrier factor LACKCAPITALFreflects lack of capital for EEMs, which has been identified as a main barrier in the literature (Anderson, Newell 2004; Rohdin et al. 2007; Sorrell 2004; Sorrell et al. 2011). In the taxonomy of Sorrell et al. (2004) LACKCAPITALF is closely related to lack of access to external capital.

Similarly, LOWPROFITFcaptures the lack of profitability of EEMs, directly via B3 and indirectly via B1.While lack of profitability may not qualify as a true barrier, i.e. as "amechanism that inhibits a decision or behavior that appears to be both energy efficient and economically efficient"(Sorrell et al. 2004), it is expected to inhibit the adoption of EEMs for profit-maximizing companies.

TRACOSTFreflects a number of barriers, mostly related to information costs and staff time, which have typically been found in the literature to impede the adoption of EEMs, includingAnderson and Newell (2004), Ostertag(2003), Schleich and Gruber (2008), Schleich (2009),TrianniandCagno(2012).The items B10, B8 and B11 reflectelement-sofhiddencostsaswellasimperfectinformation in thetaxonomyofSorrell et al. (2004). The interpretation of the findings for itemsB7 and B9is less clear. On the one hand, they may be a rational explanation for non-adoption of an EEM, and hence not qualify as a true barrier. On the other hand, since the EEMs had been suggested by energy auditors, respondents' perceptions may be wrong and the auditors' recommendation realistic and technically feasible. In this case B7 and B9 would reflect a lack of information or bounded rationality on the side of firms.

TECHRISKF captures the technical risk ofimplementing EEMs, which may lead to interruptions in production or to lower product quality. Technical risk was found to impede the adoption of EEMs, among others, in Sorrell (2004), Rohdin et al. (2007), and Thollander and Ottosson(2008), in particular if EEMs are related to the core production processes of energy-intensive firms(Anderson, Newell 2004; Dieperink et al. 2003).In the terminology of Sorrell et al. (2004), TECHRISKF falls intothe broader barrier categories of risk and hidden costs.

The factorPRIORITYFcomprises a broad set of barriers which are mainly related to internal factors internal in firms' decision-making and organizational processes. The importance of these factors for the adoption of EEMs has been highlighted by Cooremans(2011; 2012) and DeCanio and Watkins (1998). In the terminology of Sorrell et al. (2004), the items in PRIORITYF reflect a lack of access to internal capital (B2 and B12) and economic risk (B4).

The factor AUDITQUALF coverseight items that describe the respondents' satisfaction with the audit and the auditor. Audit quality shows a very high Cronbach'sα, indicating that the combined items represent a consistent factor. While these items do not directly represent an objective and comprehensive measure of an audit's quality, it seems reasonable to assume that higher quality audits translate into higher satisfaction scores.

In sum, the factors derived from the factor analysis seem consistent with the literature.The results allow the grouping of individual items into broader classes of barriers, which are largely consistent with the classification of barriers used in recent empirical studies. One point of divergence from the taxonomy of Sorrell et al. (2004) relates to the barrier category of risk. Rather than grouping technical and financial risks together in a single risk category as in Sorrell et al. (2004), our findings from the factor analysis suggest that technical and financial risks represent rather distinct barriers to energy efficiency.

Instead of identifying single important items, the factors make the underlying construct visible and allow the identification of broader patterns. Moreover, using the factors derivedfrom the factor analysis as explanatory variables for the adoption of EEMs in the subsequent econometric analysis increases the degrees of freedomand hence lowers the standard errors: Five barrier factors capture the information contained in the 15 barrier items, and one audit quality factor captures the information of eight quality items.

3.4 Econometric model

3.4.1 Dependent variable

As the dependent variable in the regression model we use the adoption rate per firm,whichis calculated as the share of adopted EEMs compared to all EEMs recommended in the energy audit. In essence, our dependent variable is comparableto the dependent variable employed bySchleich and Gruber (2009)or Schleich (2009). However, the EEMs considered in our study have been suggested by energy auditors as being suitable and profitable for the individual company.The adoption rate is neithercorrected for EEMs that were already planned before the audit nor does it include EEMs that were planned but not realized at the time the survey was conducted. The mean adoption rate of all EEMs in the sample used for the regression is 40%.[3]

By design, our dependent variable is bound between zero and one. In addition, a large share of companies has either adopted none of the EEMs recommended by the audit (40%), or all of them (27%); with high shares of observations at the boundaries, the effects of the explanatory variables tend to be non-linear and the variance tends to decrease when the mean approaches zero or one. Hence, linear regression analysis is not appropriate. Instead, we apply the fractional logit model (FLM), originally developed

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[3] By comparison, the average adoption rate in Anderson and Newell (2004) is 53 % including planned EEM.Schleich (2009) und Schleich and Gruber (2008) provide figures on the share of organizations which had adopted (or planned to adopt) at least half of the EEMs considered suitable. This share is around 35 % if only adopted EEMs are considered (Schleich 2009), and around 45 % if also planned EEMs are considered. Thollander(2007) reports adoption rates of 22 % and 41 %, respectively. The adoption rate in Harris (2000)is 81 %(not including planned EEM).

by Papke and Woolridge(1996).Using the FLM model means an improvement compared to prior multivariate regression analyses of barriers. For example, Schleich and Gruber (2008) and Schleich(2009)applylogit models after transforming the adoption rate into adichotomous dependent variable that is set to one if the adoption rate exceeds an arbitrary cut-off point of 50 % and zero otherwise. FLM avoids the loss of information resulting from the transformation of the continuousadoption rate into a dichotomous index.

3.4.2 Explanatory variables

The set of explanatory variables includesself-assessed as well as objective barriers to energy efficiency and as additional control variables also characteristics of the firm, the EEMsand theaudit itself.

Self-assessedbarriers

To capture the effects of barriers on the adoption of EEMs as perceived by the respondents, we use the barrier factors LACKCAPITALF, LOWPROFITF, TRACOSTF, TECHRISKF, PRIORITYFderived byfactor analysis in Section 3.3.Since in light of the relatively low value of Cronbach'sα, the barrier factor LOWPROFITmay not be reliable, one alternative model specification includes the original items *lackprofit*and *highinvest* in lieu of LOWPROFITF. All barrier factors are expected to have a negative effect on adoption of EEMs.Similarly, AUDITQUALF is included to reflect the impact of the perceived quality of the energy audit on adoption of EEMs. Since the form in which information is provided and the credibility of the source of information are likely to affect adoption (e.g. Sorrell et al. 2004; Stern 1984; Stern 1986) AUDITQUALF also reflects barriers related to information costs and other transaction costs. In any case, the associated parameter should be positive.

Objective barriers

In addition to the subjective factors reflecting the respondents' subjective self-assessment of barriers and audit quality on the adoption of EEMs, we also include a set of more objective factors, reflecting characteristics of the EEMs and of the firms.[4]We consider the initial investment cost of the EEMs, information on whether firms have rented their buildings, and the criterion used by firms to appraise invest-

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4The survey asked firms to report information for four of the recommended EEMs they had adopted and four EEMs they had decided not to adopt. This information included annual energy savings, investment costs and the payback time per measure. If firms adopted (or failed to adopt) more than four EEMs, we do not have an account of their characteristics..

ments in EEMs.These factors have been found in the literature review to also affect the adoption of EEMs.

Since the responses regarding the payback time of EEMs were often incomplete, we only included information on the investment cost in the regression.Information on a firm's investment costs enters the set of explanatory variables as an index. The investment cost index INVEST is calculated by the following three steps. First, since data was usually not available for all the EEMs recommended, we use the average investment costs per category of EEM (seeFigure 1).The average investment costs vary between € 400 for behavioral EEMsand€ 28,700 for building insulation. The average investment cost across all the EEMs listed in the sample is € 22,700. Second, we divide the sum of the investment cost of all the EEMs recommended to a particular firm by the number of EEMsrecommended to this firm to calculate the average costs per EEM for each firm. Finally, we divide this value by the average cost of all EEMs in the sample (€ 22,700). Thus, if the resulting index INVESTis below one the package of EEMs recommended to a particular firm is less costly than the average EEM in the entire sample, and vice versa.Higher INVEST is expected to lower the adoption of EEMs, as for example found by Anderson and Newell (Anderson, Newell 2004)

The dummy variable RENTED is set to one if a firm's office/building/production site or parts thereof are rented, partially rented or leased, and set to zero otherwise. Thus RENTED is supposed to capture the split-incentives to invest in EEMs resulting from thelandlord/tenant dilemma, and itsexpected impact on the adoption of EEMs is negative(e.g. IEA 2007). Among others, Schleich and Gruber (2008), and Schleich (2009)found that organizationsrenting buildings have a lower adoption rate than those owning the buildings.

PAYBACK takes on the value ofone if the firm uses only the payback time to assess investments in EEMs and zero if (also) other financial methods like the internal rate of return are used.Applying payback rates may reflect bounded rationality in energy-efficiency investment decisions (Stern 1984), or (extreme) risk aversion of investors, and is expected to negatively affect the adoption rate.

Although these objective barrier variables are related to broader categories of barriers like the financial capability of the firm, split incentives and bounded rationality, they can only reflect particular dimensions ofthese barrier categories.

Control variables

Finally following the literature employing multivariate analyses to study the adoption of EEMs,the set of explanatory variables also includes several control variablescapturethe effect of firm characteristics.

ECOSTSHAREstands for the share of energy costs compared to the total annual costs of the firm. The survey included the following classes for the energy cost share: <1%, 1-2%, 3-5%, 6-10% and >10%.[5] To construct ECOSTSHAREwe use the lower bound of the respective classes. Ahigher energy cost share signals higher cost-saving potentials and hence stronger economic incentives to overcome information-related barriers and adopt EEMs. Thus, we expect a higher ECOSTSHAREto be associated with a higher adoption rateas, for example found in de Groot et al. (2001), Schleich and Gruber (2008), Schleich (2009), Kostka et al. (2011),orVelthuijsen(1995).

EMANAGE is a dummy variable, which takes the value of one if the firm has an energy management system. EMANAGE is expected to have a positive impact on the adoption of EEMs, since energy management systemsshould help to overcome barriers related to lack of information and the lack of time for the implementing of EEMs(Horbach 2008; Rennings et al. 2006), and may also be seen as an indicator ofa firm's commitment to improve energy efficiency.

The survey also inquired to which extent firms had adopted EEMs in the past. Respondents could answer on a 3–point Likert scale, i.e. "scarcely", "to some extent" and "to a large extent". EHISTORY is set to one if the answer was "to a large extent" and zero otherwise. On the one hand firms that had adopted EEMsprior to the audit are also more likely to adopt recommended EEMs.In this sense, EHISTORY captures the importance of the existence of a long-term strategy for implementing EEMs (e.g. Rohdin et al. 2007; Thollander, Ottosson 2008). On the other hand, for firms which had intensively adopted EEMs prior to the audit, the remaining potential may be small, costly, or both. Hence, the expected impact of EHISTORY is ambiguous.

SIZE is measured usingthe number of employees per firm. We expect SIZE to have a positive impact on the adoption of EEMs, since, for example, larger firms face lower specific transaction costs per EEM,or are less likely to face constraints related to capital or know-how(e.g. Aramyan et al. 2007; Schleich 2009). Of course, to some extent, these aspects are also captured more directly by the self-assessedbarriers.

Table 3provides an overview of the variables used in the regression analyses.Complete data are available for 100 observations. Among others,it shows that for

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[5]The distribution of observations across the classes is as following: <1%: 12%, 1-2%: 23%, 3-5%: 34%, 6-10%: 19%, >10%:12%

this sample 26% of the firms have an energy management system installed, 61% use only payback time to assess investments in EEMs and only 6% had implemented EEMs ona large scale prior to the audit.

Table 3: Overview of variables used for the regressionanalysis (N=100)

Variable	Mean	Min.	Max.	Expected sign	Description
ADOPTRATEF	0.40	0.00	1.00		AdoptedEEMs as shareof recommended EEMs per firm.
Self-assessed barriers					
LACKCAPITALF	0.00	-1.71	2.56	–	Lack of access to external capital.
LOWPROFITF	0.00	-3.13	1.67	–	Low profitability and high initial investment cost.
TRACOSTF	0.00	-2.01	3.52	–	Transaction costs related to knowledge, time and resource constraints.
TECHRISKF	0.00	-1.54	3.65	–	Technical risk of production interruption and product quality losses.
PRIORITYF	0.00	-2.33	2.20	–	Barriers related to firms' internal process and low priority of EEMs.
AUDITQUALF	0.00	-3.67	0.97	–	Audit quality.
Objective barriers					
INVEST	1.12	0.22	2.50	–	Index of average investment costs of all EEMs recommended to a firm divided by the average investment costs of all EEMs listed in the sample.
RENTED	0.35	0.00	1.00	–	Indicator forrented or leased office/building/production site (or parts thereof).
PAYBACK	0.61	0.00	1.00	–	Indicator if onlyuse payback timeas investment criterion.
Control variables					
ECOSTSHARE	3.56	0.75	10.00	**+**	Firms' annual energy cost as share of total production costs.
EMANAGE	0.26	0.00	1.00	**+**	Indicator for energy management systemin place.
EHISTORY	0.06	0.00	1.00	**+/–**	Indicator for active adoption of EEMs in the past.
SIZE	53.6	1.00	215	**+**	Number of employees.

4. Results

We use STATA 11 to estimate the fractional logit model, which recognizes that large shares of the values for the dependent variable ADOPTRATE are at the lower and upper boundary, i.e. either zero or one.[6]Table 4 presents the findings of three specifications[7]. Model 1 includes all the barrier factors derived from the factor analysis. Since the barrier factor LOWPROFITF may not be reliable, Model 2 includes the original items *lackprofit* and *highinvest* rather than the factor LOWPROFITF. Since access to capital may be more important for EEMs withhigher investment costs, Model 3 employs INTERCAPINVEST.[8],an interaction term between LACKCAPITALF and INVEST.

As indicated by the (multiple) Wald statistics reported inTable 4, we may reject the null hypothesis that the models do not contribute to explaining the variance of ADOPTRATE. Based on the Akaike Information Criterion (AIC), which hardly differs across Model 1 to 3, a preferred modelcannot be selected[9]. However, parameter estimates and p-values hardly differ across models.

The barrier factor LACKCAPITALF, which reflects the lack of capital, is statistically significant (only) in Model 1 (at $p<0.05$). Combined with the results ofModel 3, where the interaction term INTERCAPINVEST is found to be statistically significant (at $p<0.1$), this suggests that lack of capital impedes the adoption of EEMs, but only for larger investments. While the factor LOWPROFITF is not statistically significant in Model 1, including the original items (*highinvest*and *lackprofit*) in Models 2 and 3 yields more insights. The subjective barrier *highinvest*- but not *lackprofit* - appears to impede the adoption of EEMs.

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[6] Since the sample available for the econometric analysis differs from the sample used for the factor analysis reported in

Table 2 as well as in Table 5 and Table 6in the Appendix, we recalculated the factors for the somewhat smaller sample employed in the regressions. This factor analysis reveals the same factors as before and the Cronbach'sα's are almost identical (i.e. 0.69; 0.40; 0.75; 0.92; 0.61; and 0.91 using the order of factors as in

Table 2). All results not shown are available from the authors upon request.

[7]We also ran fractional probit models to test the robustness of findings in Models 1 to 3 with respect to the assumptions about the underlying distribution. Results are virtually identical to the findings presented for the fractional logit specification.

[8]INTERCAPINVEST is calculated as the product of lack of capital and a dummy variable ofthe investment cost index which is 1 if INVEST is above 1 and 0 otherwise.

[9] The same finding holds using an alternative criterion, the Bayesian Information Criterion (BIC), which is not reported in Table 4 to save space.

Notably, no other subjective barrier turns out to be statistically significant (associated p-values tend to be well above 0.3). In comparison, we find some empirical evidence that a higher quality of the energy audit is likely to increase the adoption of EEMs: the factor AUDITQUALF is statistically significant (at $p<0.1$) in Model 3 and almost statistically significant in Model 2 (at $p<0.11$).

The only objective barrier found to be statistically significant is the investment cost index INVEST ($p<0.05$ in all three models).As expected, higher investment costs result in a lower adoption rate, corroborating the finding for the subjective barrier *highinvest*. In all models, RENTED and PAYBACK are far from being statistically significant – the associated p-values exceed 0.85.

The parameter estimate associated with ECOSTSHARE is, as expected, positive, and statistically significant at $p<0.05$ for Model 1 (p-values for Model 2 and 3 are 0.11 and 0.16 respectively). Hence, our findings provide some empirical evidence that more energy-intensive firms assign a higher priority to energy efficiency.

Employing an energy manager tends to increase the adoption of EEMs, but the parameter associated with EMANAGE is not statistically significant (p-values are around 0.2 for Models 2 and 3, and 0.4 for Model 1). Similarly, active adoption of EEMs in the past (EHISTORY) appears to have no effect on the current adoption rates of EEMs (p-values > 0.5 in all models). As discussed earlier, this outcome may be the result of countervailing effects: a higher EHISTORY may reflect a higher propensity to adopt EEMs in general, but may also indicate that there are fewer cost-efficient EEMs left.Finally,the parameter associated with company SIZE is not statistically significant.

Table 4:Results of fractional logitregressions (robust standard errorsin parentheses)

Dependent Variable: ADOPTRATE	(1)			(2)			(3)		
LACKCAPITALF	-0.29	*	(0.13)	-0.11		(0.14)	0.40		(0.37)
INTERCAPINVEST							-0.60	*	(0.36)
LOWPROFITF	0.08		(0.14)						
highinvest				-1.03	***	(0.39)	-0.99	**	(0.41)
lackprofit				0.38		(0.31)	0.32		(0.31)
TRACOSTF	0.09		(0.10)	0.08		(0.11)	0.08		(0.10)
TECHRISK	0.15		(0.10)	0.09		(0.10)	0.07		(0.10)
PRIORITY	0.07		(0.13)	0.02		(0.14)	0.01		(0.13)
AUDITQALF	0.13		(0.11)	0.17		(0.11)	0.18	*	(0.11)
INVEST	-0.80	*	(0.38)	-0.86	**	(0.39)	-0.89	**	(0.40)
RENTED	0.03		(0.26)	0.01		(0.25)	0.02		(0.24)
PAYBACK	-0.03		(0.28)	0.00		(0.28)	0.05		(0.29)
ECOSTSHARE	0.09	*	(0.04)	0.08		(0.05)	0.07		(0.05)
EMANAGE	0.22		(0.27)	0.34		(0.29)	0.39		(0.29)
EHISTORY	0.25		(0.74)	0.31		(0.65)	0.40		(0.64)
SIZE	-0.10		(0.10)	-0.14		(0.11)	-0.17		(0.11)
Constant	0.42		(0.60)	1.23	**	(0.60)	1.37	**	(0.61)
Sample size	100			100			100		
-log likelihood	-48.9			-47.9			-47.6		
aic	1.259			1.259			1.272		
Wald statistic (p-value)	27.45 (0.011)			32.80 (0.003)			33.80 (0.004)		

Note: *** indicates significance at p=0.01. ** indicates significance at p=0.05 and * indicates significance at p=0.1 in individual two-tailed t-tests

5. Discussion

In this section we discuss the findings of ourempirical analyses and derive implications for policymaking. We also relate our findings to the literature, in particular to studies which also rely on data from stand-alone energy audit programs.

The first, and arguably clearest, finding of our regression analyses is that high investment costs, which are captured by both subjective and objective variables in our model, appear to impede the adoption of EEMs. Similarly, we find that *lack of capital* slows EEM adoption, primarily for larger investments. When combined, these findings underline the fact that lack of*access to capital* is a crucial barrierinthe decision to adoptEEMs, even when they are profitable. Among others, Anderson and Newell (2004)and Thollander et al. (2007) (but not Harris et al. 2000) also conclude that the *initial investment costs* negatively affect the adoption rate. Hence, while this finding per se is not a novel one, our analysis provides a statistically-supported foundation for policy design, at least for the German audit program. Specifically, our findings suggest that investment subsidies or soft loans are effective policy measures to accelerate the diffusion of EEMs in SMEs. The net benefits would be highest if support were limited to larger investments. In addition, promoting energy service contracts via energy services companies (ESCOs)couldalso be effective in overcoming finance-related barriers(see e.g. Marino et al. 2011; Mills 2003). As most EEMs are cross-cutting (or ancillary) technologies, which are similar across firms, ESCOs could benefit from providing standardized solutions. However, energy services companies may be hesitant to do so, becauseSMEs bearhigher financial risks than larger companies or public organizations, and because theindividual projects are relatively small.In addition,energy audits could be linked with energy-efficiency obligations and white certificate schemes, which are already in place in several European countries (Bertoldi et al. 2010). For example, such a scheme could recognize energy savings identified and certified by an independent auditor. This could contribute to overcoming finance-related barriers, as utilities (or other entities that are subject to the energy-efficiency obligation) would be responsible for financing the measures. Such a link would also make it easier to extend the scope of white certificate schemes from mostly simple standardized measures to more complex measures, and enable larger energy-efficiency gains to be realized by these schemes.

Companysize appears to have no effect on the adoption of EEMs. This is somewhat surprising, since most empirical studies (Aramyan et al. 2007; Schleich 2009) – but not all (Anderson, Newell 2004) – find that larger firms are more likely to adopt EEMs. Since our multivariate analysis includes a comparatively broad set of explanatory variables, sizeeffects may also be picked up by some of the other variables. For example, larger firms face lower specific transaction costs per EEM, or are less likely to face constraints related to capital resources or know-how (e.g. de Groot et al. 2001). On the other hand, Velthijsen(1995) presents some evidence that larger firms with more complex decision-making processes may be even slower in adopting EEMs. An alternative explanation is thatoursample of SMEs may not provide sufficient variation in firm size to produce statistically significant effects,because firms with more than 250 employees are not eligible for support under the German energy audit program.In other words, sizeeffects are more likely to be detected insamples which also include larger firms, as was the case in the US IAC program(Anderson, Newell 2004).

In our analyses, technical risks like production interruption or loss of product quality were not found to be statistically significant barriers. This finding may be rationalized by the way the dependent variable is constructed. The adoption rate of EEMs tends to be dominated by thoserelated to ancillary processes rather than to core production processes.Ourresults provide some evidence, however, that the energy cost share of a firm positively affects the adoption rate, supporting the findings by de Groot et al. (2001), Schleich and Gruber (2008), Schleich (2009), and Velthuijsen (1995). Higher cost shares indicatehigher cost-saving potentials and higher economic returns on companies' efforts to surmount the barriers to energy efficiency. Alternatively, a higher cost share may signal a higher strategic relevance for the company and may thus automatically attract attention from top management (Cooremans 2011). In this case, lack of capital (as a result of internal priority setting) should be less of a barrier.

Besides *lack of capital* and *investmentcost* related barriers, no other barrier considered in the econometric analysis was found to be statistically significant in our sample. This finding differs from the majority of the literature on barriers to energy efficiency in SMEs, which suggests that SMEs typically face multiple barriers (Gruber, Brand 1991; Schleich 2009; Schleich, Gruber 2008; Thollander et al. 2007). As the survey in this study was conducted after the energy audits had been carried out, one possible interpretation of our finding is that the audits effectively removed these barriers.Notably, Anderson and Newell (2004), Thollander et al. (2007) and Harris et al. (2000)also find that energy audits contributed to removing barriers related to *information and other transaction costs for gathering knowledge about EEMs*. In light of the relatively small sample size and the absence of a control group, such an interpretation canonly be tentatively suggested in our case and further research is required for validation.

It should also be kept in mindthat the lack of data did not allow us to explore barriers at the level of individual EEMs. Insights into EEM-specific factors could be gained by following an approach similar toAnderson and Newell (2004), for example.

Our findings also provide evidence that the *quality of the energy audits*(measured by satisfaction with the audits) affects the adoption of EEMs. Although this finding is not very surprising, our study is the first which enablesthe corresponding policy recommendations to be made based on a statistical analysis. The EU Directive for Energy End-Use Efficiency and Energy Services(European Union 2006) requires EU Member States to ensure that final consumers have access to efficient and high quality energy audits. In addition, the proposal for the EU Energy Efficiency Directive (European Commission 2011)calls onMember States to establish energy audit programs for SMEs. Our results suggest that these regulations as well as energy audit regulations in other regionsshould include measures addressing the quality of the energy audit. For example, standards for energy audits could be developed, such as the European energy audit standard that is currently under way(DIN prEN 16247-1 2011). For the German audit program, mandatory report templates and quality requirements for auditors (e.g. three years of work experience and an engineering degree or similar) already exist. But similar to most other existing programs (Price, Lu 2011), a specific certificate is not required. Further, software tools and standardized methodologies to support the analytical part of the audit could further improve its quality and ensure that the major potentials for efficiency improvements are addressed (see for example Cagno et al. 2010). Finally, as is already the case for several audit programs, (mandatory) follow-up cooperation between the auditor and the firm could be introduced (Price, Lu 2011).Such follow-up activitiescould range from simple telephone calls to much closer cooperation to implement more complex EEMs. Also ex-post evaluations could contribute to ensuring audit quality. To save costs, rather than including all the companies participating in an audit, such evaluations could be limited to randomly selected companies.

As a caveat, our findings should be interpreted with caution in view of the relatively small sample size. More observations would lead to lower standard errors, ceteris paribus, and more barriers and control variables mightbecome statistically significant. To save degrees of freedom, we also ran additional regressions omitting all explanatory variables where parameter estimates are far from being statistically significant (implemented as $p>0.5$). The results for the remaining variables barely changed compared to those presented inTable 4.

6. Conclusions

We used multivariate regression analysisto investigatethe effects of a broad range of factors on the adoption of energy-efficiency measuresin German SMEs. Ouranalyses are based on a unique dataset compiled from a 2010 survey of SMEs which had participated in the German energy audit program. In particular, the EEMs considered in our analyses had been identified ascost-efficient following detailed firm-specific engineering-economic investment appraisals by professional energy experts. Subjective factors are derived via factor analysis from a large set of individual items and include self-assessed barriers to energy efficiency reflecting lack of capital, lack of profitability, transaction costs, technical risks, priority setting/uncertainty and the perceived quality of the audit. The objective factors considered include investment costs, the landlord-tenant dilemma and the use of payback time. In addition, control variables are included in the econometric analysis to account for the effects of firm-specific factors like energy-intensity, energy management, past energy-efficiency activity, and firm size.

Since the range of the dependent variable (adoption rate) is between zero and one, and since a large proportion of observations are at the upper and lower bounds, we employ a fractional logit model. Compared to previous multivariate analyses of barriers to energy efficiency, using the FLM model offersa more efficient use of information. Our findings from the regression analysis are generally robust to alternative model specifications and are consistent with the theoretical and (still rather scarce) empirical literature on barriers to energy efficiency in SMEs. Our resultsidentify high initial investment costs as a main barrier to the adoption of EEMs. Thus, to accelerate the adoption of EEMs via audit programs, theseshould be accompanied by financing programs. Further, we find evidence that the quality of the energy audits also affects firms'propensity to implement the suggested EEMs.This result rationalizes policy regulation which includes measures to ensure a high quality of the energy audits, such as templates for audit reports, certification of auditors, ex-post evaluations, or mandatory monitoring of energy audits.

Our findings for the factor analysis of the subjective barrier items by and large validate the theoretical framework and barrier taxonomy previously used in the literature to conceptualize and empirically analyze barriers to energy efficiency. Hence, results from the factor analysis allow the barriers to energy efficiency to be considered at a more abstract level than individualconcrete obstacles.As a point of discrepancy to the broader barrier categories developed bySorrell et al. (2004), our results suggest that technical and financial risks do not fall into the same broader barrier category, but instead represent distinct barriers to energy efficiency.

Future research could apply a similar factor analysis toother sectors or countries, using additional barrier items or EEM-specific information to validate and refine our approach and further enhance the taxonomy of barriers to energy efficiency for empirical and conceptual analyses.

Appendix

Table 5: Results of the factor analysis using theprincipal component factor method for self-assessedbarrier variables

Factor analysis/correlation		Number of observations	=	138
Method: principalcomponent factors		Retained factors	=	5
Rotation: (unrotated)		Number of parameters	=	65

Factor	Eigen-value	Difference	Proportion	Cumulative
Factor 1	3.985	2.130	0.265	0.265
Factor 2	1.854	0.439	0.123	0.389
Factor 3	1.415	0.108	0.094	0.483
Factor 4	1.306	0.154	0.087	0.570
Factor 5	1.151	0.267	0.076	0.647
Factor 6	0.884	0.044	0.059	0.706
Factor 7	0.839	0.119	0.056	0.762
Factor 8	0.720	0.128	0.048	0.810
Factor 9	0.591	0.040	0.039	0.849
Factor 10	0.551	0.057	0.036	0.886
Factor 11	0.493	0.031	0.032	0.919
Factor 12	0.462	0.087	0.030	0.950
Factor 13	0.374	0.124	0.025	0.975
Factor 14	0.249	0.128	0.016	0.991
Factor 15	0.120		0.008	1.000

Table 6: Results of the factor analysis using theprincipal component factor method for self-reported audit quality variables

Factor analysis/correlation		Number of observations	=	437
Method: principalcomponent factors		Retained factors	=	1
Rotation: (unrotated)		Number of parameters	=	8

Factor	Eigen-value	Difference	Proportion	Cumulative
Factor 1	5.283	4.509	0.661	0.661
Factor 2	0.775	0.206	0.097	0.757
Factor 3	0.569	0.187	0.071	0.829
Factor 4	0.382	0.051	0.048	0.876
Factor 5	0.332	0.029	0.041	0.918
Factor 6	0.303	0.092	0.038	0.955
Factor 7	0.210	0.065	0.027	0.982
Factor 8	0.145	-	0.018	1.000

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