Credit Constraints, Energy Management Practices, and Investments in Energy Saving Technologies: German Manufacturing in Close-up

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Abstract

We analyze the drivers and barriers that influence investments increasing the energy efficiency of firms' production processes or buildings in the German manufacturing sector based on microdata. In particular, we shed light on the relationship between financial barriers (e. g. credit constraints), information and knowledge (e. g. energy management practices), salience of energy-related topics, and the investments in energy saving technologies. A better understanding of firms' investment behavior regarding energy saving technologies is crucial to design efficient policy measures, which are necessary to achieve the imposed ambitious climate and energy policy targets. We use data from 701 structured telephone interviews in combination with commercial and confidential firm-level data. Our results suggest that energy management practices have a statistically significant positive relationship with investment decisions on energy saving technologies for production processes and buildings. Credit constraints are a barrier to investments in the energy efficiency of firms' production processes. Furthermore, high energy cost shares of heating or cooling, high energy intensity, energy self-generation and structured internal decision making processes influence the investments in energy efficiency positively.

Keywords: Energy efficiency, Credit constraints, Energy management, Manufacturing industry, Investment behavior

JEL: D22, H23, Q41, Q48, Q58

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1 Introduction

The use of energy from conventional sources involves negative externalities at the local and global scale. Accordingly, decreasing fossil energy use due to increasing energy efficiency offers economic and societal benefits through the reduction of costs, environmental damage, and import dependencies. That is why energy efficiency has a high priority on energy and climate policy agendas in many countries.

Germany aims at almost doubling its annual improvements in economy-wide energy productivity[1] to 2.1 percent. However, the German economy is currently not on the trajectory to reach this ambitious energy efficiency target. Official statistics show that energy productivity only increased by about 1.3 percent per year during the period from 2008 to 2015 (BMWi, 2016; Löschel et al., 2016). Consequently, drivers of and barriers to energy efficiency improvements have to be identified and there is a strong need for efficient policy instruments to foster energy efficiency.

The manufacturing sector is a large energy user and an important cornerstone of the German economy. In 2014, it accounted for 30 percent of final energy use and 22 percent of gross value added (BMWi, 2015). In order to achieve the superordinate targets, it will be essential to also increase energy efficiency in manufacturing and thus necessary to adopt energy saving technologies. The objective of this study is to shed light onto the drivers and barriers that influence investments in energy saving technologies by German manufacturing firms and to provide insights for the design of energy efficiency policies. More specifically, we analyze the relationship between financial barriers, lack of information and knowledge, salience of energy-related topics, and the investments in energy saving technologies.

The economic literature points to the fact that energy saving technologies, which promise considerable reductions of financial costs and environmental damage associated with energy use, may not be adopted by firms to the degree that might be justified, even on a purely financial basis (Gerarden et al. 2017). In Germany a portfolio of policy instruments has been implemented in order to incentivize the adoption of energy saving technologies. However, the effectiveness of these measures falls short of expectations, thus the policy targets will most likely not be met (Löschel et al., 2016). This shortcoming can be explained by the so called energy efficiency gap. This gap arises as market failures or behavioral obstacles hinder firms from achieving their individually profitable levels of investments in energy efficiency (Gerarden et al., 2017; DeCanio, 1993). In a recent study, Hochman and Timilsina (2017) quantify economic, behavioral, and institutional barriers to investments in energy-efficient technologies using Ukrainian data of commercial and industrial firms. They find that a lack of information, knowledge, and awareness are major barriers. Furthermore, financial barriers are especially relevant for small firms. A broader overview of empirical studies addressing the role of barriers to the adoption of energy efficiency measures at the firm level can be found in Fleiter et al. (2012).

[1] Here, energy productivity is defined as price adjusted gross domestic product divided by total final energy consumption.

The empirical literature has demonstrated that firms from the manufacturing sector are subject to the energy efficiency gap. De Groot et al. (2001), DeCanio (1998), and DeCanio and Watkins (1998) investigate how economic and organizational firm characteristics are related to investments in energy saving technologies. Martin et al. (2012) as well as Boyd and Curtis (2014) show that management practices affect the energy efficiency of firms depending on the applied management scheme. In particular, Martin et al. (2012) show that energy targets set internally by firms decrease their energy intensity. They conclude that "(...) management practices and organizational structure of a firm are crucial for its ability to use energy more efficiently." We contribute to this strand of literature by examining how investments in energy saving technologies are related to firm characteristics, and information and knowledge, especially energy management practices.

In addition, we investigate the role of credit constraints for these investments. Schleich and Gruber (2008) identify restricted access to capital markets as an important barrier to investing in energy efficiency. Also, Allcott and Greenstone (2012) state that credit constraints are frequently discussed as an obstacle to investments in energy saving technologies. However, due to the lack of empirical evidence this discussion has remained mostly theoretical (cf. Gillingham et al., 2009; Gillingham and Palmer, 2014). Rohdin et al. (2007) show that a lack of budget funding and access to capital are among the top three self-reported barriers to the implementation of energy efficiency measures. We extend this strand of literature regarding financial barriers by examining the link between firm-specific credit worthiness based on credit rating agency data and investments in energy saving technologies.

We conduct a correlation analysis to investigate the decision to invest in energy saving technologies at the firm level by employing different linear and nonlinear regression models. Our empirical analysis exploits two main data sources. First, we use data from structured telephone interviews that we conducted with managers of 701 randomly selected German manufacturing firms. This unique survey data contains information on the investments in energy saving technologies with respect to firm's production processes or buildings. Furthermore, it includes information on energy management practices and internal investment-related decision making processes. Second, we merge this data with commercial microdata including general firm characteristics from official sources as well as firm-level credit ratings from Germany's largest credit rating agency.

Utilizing this detailed data set, we can analyze two different investment categories of energy saving technologies separately and jointly, i. e. for production processes and for buildings. The investment frameworks for both categories differ from each other, for example, due to technological aspects or the policy framework. Thus, we would suggest that the drivers and barriers regarding each investment category are different. However, we can identify this heterogeneity utilizing the aforementioned data set. Furthermore, we contribute to the literature by using external credit rating data instead of self-reported information to determine the role of financial barriers. Thus, we can identify whether financial barriers are important for the investment decision applying objective data provided by Germany's largest credit rating agency.

Additionally, we add a more up to date analysis of the energy efficiency gap to the literature analyzing German firms, e. g. compared to Schleich and Gruber (2008), and can therefore provide insights from the current policy framework for policy makers. It relies on representative survey data amongst German manufacturing firms. The discrete investment decision is analyzed using a probit model. Additionally, the analysis includes the combined estimation of the investment decision and the investment volume, applying two-part and Heckman selection models.

We find that credit constraints are barriers to investments in energy saving technologies which increase the energy efficiency of firms' production processes and that energy management practices increase the probability of investing in the energy efficiency of their production processes. Furthermore, investments in the energy efficiency of buildings are also positively influenced by implemented energy management practices. The higher the energy cost shares of heating or cooling and the energy intensity of firms, the higher is the propensity to invest in energy efficiency. In addition, energy self-generation by firms as well as structured internal decision making processes influence the investments in energy efficiency positively.

The remainder of the paper is organized as follows: In section 2, we give an overview over German energy efficiency policies. In Section 3, we develop a theoretical model and derive specific research hypotheses. In Section 4, we describe the analyzed data sets. Afterwards, we briefly explain our empirical strategy in Section 5. We discuss the results of our empirical analyses in Section 6. Section 7 provides our concluding remarks.

2 Energy efficiency policies in Germany

The reduction of greenhouse gas emissions and the phase out of nuclear power are the overarching policy goals of the current energy and climate policy agenda of Germany. Energy efficiency and the increase in renewable energy in all sectors of the economy are core objectives to achieve these goals (BMWi, 2016; Löschel et al., 2016). Since the year 2010 the German energy policy agenda has been subsumed under the framework of the Energy Transition ("Energiewende") after the German federal government published an energy concept. This concept includes a long-term strategy and targets, which are mostly to be reached by 2050, as well as policy measures for various energy and climate policy areas. However, even before the year 2010 energy efficiency policies were in force. The main goals for energy efficiency and energy consumption are summarized in Table 1.

To reach the energy efficiency targets and operationalize their implications various policy measures have been implemented. These target different sectors and stakeholders, like energy utilities, transport, buildings, industries, households, or consist of multi-sectoral policies. We focus on policy measures targeting the production processes and buildings in the manufacturing sector or specific multi-sector policies.[2]

[2]A comprehensive overview of energy efficiency polices in Germany can be found in the Policies and

Table 1: Quantitative targets of the Energy Transition: energy efficiency and consumption

		Status		Target	
	Compared with	2013	2015	2020	2050
Primary energy consumption	2008	-3.8%	-7.6%	-20%	-50%
Final energy productivity	(2008-)	0.2% p. a.	1.3% p. a.	-	2.1% p. a.
Gross electricity consumption	2008	-3.2%	-4%	-10%	-25%
Primary energy consumption in buildings	2008	-5.5%	-15.9%	-	-80%
Heat consumption in buildings	2008	0.8%	-11.1%	-20%	-

Notes: Sources: BMWi (2016, 2014)

First of all, from an economic perspective, increasing energy prices, especially electricity prices, in recent years should have incentivized firms to invest in energy saving technologies for both production processes and buildings. Many of the drivers of the price increases are components induced by regulation, resulting from policies like the German electricity or energy tax, the European Union Emissions Trading Scheme (EU ETS), or the German renewable energy surcharge. Many firms in the manufacturing sector are exempt from these policies to minimize the risk of losing international competitiveness due to incomplete global regulation. Nonetheless, a non-negligible share of firms remain subject to these policies, as various thresholds for eligibility apply. In some cases these exemptions are conditional on certain requirements. For example, energy tax reliefs for manufacturing firms "(...) are linked to energy efficiency measures such as implementation of energy management systems and achieving energy efficiency targets" (IEA, 2013).

In addition to these general incentives to use energy more efficiently due to increasing prices and price-based policy instruments, there is a distinction between two main fields of action in energy efficiency policies targeting manufacturing firms: the energy efficiency of production processes and buildings (BMWi, 2017a). Thus, these areas are tackled by differentiated policy instruments. Both areas are characterized by different technological and organizational requirements, which are reflected in the respective policy measures. Technologies applied in the production processes are linked directly to the key processes of productive firms, which are often characterized by industry- or even firm-specific heterogeneities. Technologies used for energy efficiency improvements of buildings are more often cross-cutting technologies. These technologies cannot only be utilized in a specific industry or firm, but in manifold areas of application and sectors.

Regarding the production processes of firms there are mostly information and education as well as financial support policies in place. Furthermore, there are standards for industrial products and production processes to increase their energy efficiency. A list of relevant policies can be found in Table 14 in Appendix A.

The energy efficiency of firms' buildings are predominantly regulated by standards and subsidy schemes, like publicly subsidized loan programs. The most important poli-

Measures Databases provided by the International Energy Agency (IEA) (IEA, 2017).

cies for buildings are the Energy Saving Act (EnEG) and Energy Saving Ordinance (EnEV), which were introduced in 2002 and include not only regulations for residential buildings but also non-residential buildings. These incorporate minimum requirements for the energy efficiency of buildings, mostly for new buildings. Furthermore there are large financial incentive programs in place, which provide subsidized loans. An overview of policy measures regarding the energy efficiency of firms' buildings can be found in Table 15 in Appendix A.

Overall, there are two options to reduce greenhouse gas emissions from buildings' energy use, which can be implemented either in combination or individually. These measures include the reduction of energy use by increasing energy efficiency and using renewable energy sources to produce the thermal energy needed without using fossil fuels. The policy framework targets both of theses measures at the same time. As stated by the German Federal Ministry for Economic Affairs and Energy: "The Federal Government wants to make Germany's building stock virtually climate-neutral by 2050. In order to do this, more of our heating needs to be covered by renewables and our buildings made more energy-efficient." (BMWi, 2017b)

3 Theoretical decision model of firms' investments in energy saving technologies

Investments in energy saving technologies, similar to general investment decisions of firms, depend on various factors and are based on internal firm decision processes. In the following, we develop an analytical framework regarding investments in energy saving technologies and subsequently derive our research hypotheses. We assume a profit-maximizing firm which faces the decision whether to invest in energy saving technologies. According to the standard neoclassical theory of investment, profit-maximizing firms should undertake all investments with a positive net present value (NPV) (DeCanio and Watkins, 1998). The probability of investing, that is the NPV is greater or equal than zero, is a function of a variety of factors. The investment decision with respect to energy saving technologies fundamentally involves a trade off between higher initial capital costs and uncertainty about future energy costs and cost savings. These capital costs have to be weighted against the expectation of future cash flows (Gillingham et al., 2009).

We extend a basic NPV model, cf. Brealey et al. (2011), in order to discuss potential drivers of and barriers to investments in energy saving technologies. The net present value NPV is the difference between the investment's value and its cost. It is determined by

$$NPV = \sum_{t=1}^{T} \frac{1}{(1+r)^t} \Big(\theta\mu(E_0 - E')p_t^E - C_t^B(I_0, A, \phi, \sigma) \Big) - I_0, \quad (1)$$

where t denotes the year, T the project lifetime and r the firm's discount rate.

The energy use of the firm is defined by E_0 before and by E' after the adoption of the newly installed technologies. The energy saving is valued at the firm's expected energy price p_t^E. The future cash flows have to be weighted against different costs. First of all the upfront investment costs I_0 are relevant for the investment decision. Furthermore, we include borrowing costs in our model given by $C_t^B(\cdot)$.

It is possible that the firm does not fully anticipate the energy savings from the investment in energy saving technologies due to a lack of *information* or *knowledge*; this is represented by $\theta \in (0,1)$. The better the firm is informed about energy use and available energy saving technologies, the larger is θ (cf. Hochman and Timilsina, 2017). As stated by Allcott and Greenstone (2012) imperfect information could be the most important form of investment inefficiency causing the energy efficiency gap. More comprehensive information can be obtained, for example, by using different energy management practices, such as energy management systems (EMS) or the regular assessment of the energy efficiency potential. After employing these practices, firms should be more likely to invest as they have more and better information about the firm's energy use and available energy saving technologies. Another relevant factor is the usage of internal decision making processes for the evaluation of investment projects regarding energy saving technologies. For these investment appraisal calculations, detailed information about the proposed investment projects are necessary and thus gathered and evaluated (Sandberg und Söderström, 2003). This information could include different investment options, energy use and savings, and other technical or energy-related specifications.

Other aspects are *salience* and *awareness* of energy-related topics. The more salient or important the topic 'energy' is for firms, the higher is their appreciation of investments in energy saving technologies. These firms should thus be more aware about energy-related indicators and information. This relationship is represented by $\mu \in (0,1)$, whereby the larger μ, the larger the importance of energy in general to the firm. This is most importantly proxied by overall energy costs or a firm's energy intensity. Schleich and Gruber (2008), for example, state that firms from energy intensive industries tend to be more aware of the potential cost savings from investments in energy efficiency. Economic incentives are likely to be higher for those with a higher energy cost share. Thus, firms with a higher energy intensity[3] should be more inclined to invest in energy saving technologies because energy is a more important cost factor and energy savings are more relevant to the firms. Additionally, different cost shares could play a role in the investment decision; as we differentiate between investments in production processes and buildings, we take the share of heating and cooling in total energy costs into account. Thus, the higher the energy cost share for heating and cooling, the higher could be the incentive to invest in the energy efficiency of buildings and the lower to invest in the energy efficiency of production processes. The investment in the energy efficiency of buildings could also be influenced by their ownership status and the associated problem of split-incentives. The salience of energy-related topics might also be triggered by firms' energy self-generation. Firms which self-generate energy have to take additional energy-related factors into account, like the optimal utilization of the energy generation unit or

[3] We calculate energy intensity as energy costs per turnover similar to Martin et al. (2012).

selling excess energy.

When offsetting the cash flows, the firm's borrowing costs as well as *financial barriers and incentives* have to be considered. These are given by $C_t^B(\cdot)$ in Equation 1 and are a function of the size of the investment I_0, the equity share A, financial barriers ϕ, here creditworthiness, and received subsidies. The investment is financed either by equity or borrowed capital. Mostly firms need to borrow $I_0 - A$, because $A < I_0$. The equity share and the borrowing costs depend on different factors, such as firm characteristics or external conditions. Czarnitzki and Kraft (2007) show that credit ratings, which represent the creditworthiness of a firm, have additional information value for lenders and therefore serve as an indicator of firms' ability to raise external funds for their investments. Firms with lower credit ratings should face more difficult conditions when using their equity or borrowing money. Thus, on the one hand, the opportunity cost of the investment increases and worsens the NPV of the investment. On the other hand, the borrowing costs could be reduced by policy measures, e. g. publicly financed subsidy schemes, fostering the adoption of energy saving technologies and thus helping to reach the overall energy efficiency targets, independently of the other borrowing conditions. The barrier is lower for firms that receive publicly subsidized loans for their investment on energy saving technologies and consequently reduces the borrowing costs. The cash flows from energy cost savings and the borrowing costs are discounted over the project lifetime.

Table 2: Influencing factors for firms' investment decisions on energy saving technologies

Category	Factor	Influence on NPV	
		production processes	buildings
Information & knowledge (θ)	Energy management practices	+	+
	Decision making processes	+	+
Salience & awareness (μ)	Energy intensity	+	+
	Share of heating or cooling in energy costs	−	+
	Buildings' ownership	n/a	+
	Energy self-generation	+	+
Financial barriers (ϕ)	Credit rating	+	+
	Subsidies	+	+

Notes: A positive (+) (negative (−)) sign indicates that if a factor is positive or increases, the NPV calculation gets more positive (negative) and thus the probability of investing is higher (lower).

We summarize the influencing factors analyzed in our paper and their potential influence on the investment decisions in Table 2. We will test these hypotheses empirically in what follows and hence analyze the investment decisions on energy saving technologies of German manufacturing firms.

4 Data

To investigate our research question empirically, we use the results of structured telephone interviews combined with commercial and confidential firm-level data. The survey sample and further firm data were selected from the Mannheim Enterprise Panel, a microdata base of companies in Germany.

Table 3: Overview of variables

Variable names	Type	Values
Investment decision on energy saving technologies (EST) for prod. proc. 2013	Dummy	[0/1]
Investment volume of EST for prod. proc. 2013	Continuous	Euros
Investment decision on EST for buildings 2013	Dummy	[0/1]
Investment volume of EST for buildings 2013	Continuous	Euros
Creditreform Solvency Index 2011	Continuous	[100-600]
Creditreform Rating 2011	Categorical	[1/2/3/4/5/6]
Assessment of energy efficiency (EE) potential	Dummy	[0/1]
Energy consumption targets	Dummy	[0/1]
Energy management system	Dummy	[0/1]
One energy management practice implemented	Dummy	[0/1]
Two energy management practices implemented	Dummy	[0/1]
Three energy management practices implemented	Dummy	[0/1]
Energy costs 2011	Continuous	Euro
Share of heating or a/c in energy costs 2011	Continuous	[0-1]
Ownership of buildings	Dummy	[0/1]
Self-generation with fossil fuels	Dummy	[0/1]
Self-generation with renewable energy sources (RES)	Dummy	[0/1]
Investment appraisal - general	Dummy	[0/1]
Investment appraisal - EST	Dummy	[0/1]
Investment appraisal - more restrictive criteria for investments in EST	Dummy	[0/1]
Publicly subsidized loans received - prod. proc.	Dummy	[0/1]
Publicly subsidized loans received - buildings	Dummy	[0/1]
Number of employees	Continuous	Head count
Age of the firm	Continuous	Years
Sales share of the most important customer	Continuous	[0-1]
Exporting company in 2011	Dummy	[0/1]
Part of a group	Dummy	[0/1]
International location of production	Dummy	[0/1]

4.1 Firm-level and survey data

Commercial firm-level data — Our main data source is the Mannheim Enterprise Panel (Mannheimer Unternehmenspanel; MUP), which is maintained by the Centre for European Economic Research (ZEW). The MUP is the most comprehensive census database of firms in Germany outside the official business register. The MUP is based on the firm data pool of Creditreform e.V., which is the largest credit rating agency in Germany. The MUP serves as a foundation for many firm-level data sets, for instance the German data products of Bureau van Dijk. At the end of 2013, the MUP contained information on about 3.2 Mio active firms. According to Bersch et al. (2014), comparisons of the active stock of firms in the MUP with the Business Register of the Federal Statistical Office indicate that the MUP gives by and large a representative picture of the corporate landscape in Germany.

Table 4: General firm characteristics

Variables	Obs	Mean	Std. Dev.	Min	Max	P50
Turnover 2013 (in 1000 EUR)	666	41,337.79	167,941.7	100	2,048,038	5,500
Turnover 2011 (in 1000 EUR)	689	31,417.19	141,219.6	10	2,000,000	5,100
Number of employees 2013	637	89.18	252.01	20	5,773	42
Number of employees 2011	690	82.14	236.35	20	5,773	40
Total investments 2013 (in 1000 EUR)	634	1,449.08	5,726.22	0	100,000	200
Firm's age	701	36.21	45.02	0	635	24
Exporting firm in 2011	576	0.6	0.49	0	1	1
Location in East Germany	701	0.2	0.4	0	1	0
Part of a group	701	0.26	0.44	0	1	0
International location of production	695	0.17	0.38	0	1	0

Interviews — During the period from November 2014 to January 2015, we conducted structured telephone interviews[4] with managers of 701 German manufacturing firms. The average interview lasted 20 minutes. Our data basis is the aforementioned MUP and contains general information of each firm. We drew a random sample of 5,668 firms from the MUP and contacted the firms by telephone in order to identify adequate contact persons. By request, interviewees were sent a letter with information about the survey, which also assured confidentiality, before the interview.

We successfully contacted 4,816 companies, of which 2,468 declined to participate. 69 started the interview, but did not finish it. In 1,578 cases interviewers were asked to call back at another time or made an appointment with the contact person. However, interviews were only carried out until the target number of 700 interviews was reached. Counting only interviews granted and declined explicitly, we obtain a response rate of 22 percent.

For an overview of the information solicited see Table 3. The 701 interviewed firms represent a wide variety of activities, sizes, ages, international activities, and different types of ownership. Descriptive statistics on general firm characteristics and economic activities are shown in Tables 4 and 5. In order to rule out selection bias, we analyze observable firm characteristics for respondents and non-respondents. The issue of selection bias might arise if interviewed firms differ systematically from firms that declined to be interviewed. We examine this issue in Appendix B and find no evidence that our sample is non-random.

4.2 Variables and descriptive statistics

Investments in energy saving technologies (EST) — We asked firms to report (i) whether they had invested in energy saving technologies in the past, (ii) if they had invested in 2012 or 2013, and (iii) which amount they spent in case they had invested in 2012 or 2013.

[4]The interviews were carried out by the Umfragezentrum Bonn - Prof. Rudinger GmbH (uzbonn GmbH) - a company specialized in surveys and evaluations.

Table 5: Distribution of economic activity in 2013

NACE two-digit	Economic activity	Analysis sample Number	Analysis sample Percent	Whole manufacturing sector Percent
10	Food products	96	13.69	12.82
11	Beverages	11	1.57	1.25
13	Textiles	7	1.00	1.74
14	Wearing apparel	8	1.14	0.71
15	Leather products	2	0.29	0.32
16	Wood and cork	19	2.71	2.66
17	Paper and paper products	14	2.00	2.09
18	Print and recorded media	25	3.57	3.43
19	Coke and refining	2	0.29	0.13
20	Chemicals	21	3.00	3.29
21	Pharmaceutical	2	0.29	0.70
22	Rubber and plastic	67	9.56	7.51
23	Non-metallic mineral products	18	2.57	4.08
24	Basic metals	22	3.14	2.45
25	Fabricated metal products	148	21.11	18.65
26	Computer, electronic and optics	40	5.71	4.46
27	Electrical equipment	30	4.28	5.20
28	Machinery and equipment n.e.c.	109	15.55	14.45
29	Motor vehicles	13	1.85	2.76
30	Other transport equipment	5	0.71	0.70
31	Furniture	11	1.57	2.61
32	Other manufacturing	21	3.00	3.88
33	Repair and installation	10	1.43	4.21
	Total	701		

Notes: Based on the NACE two-digit industry level. The data for the whole manufacturing sector in the last column are derived from the Federal Statistical Office of Germany. The total number of firms in 2013 is 36,609 (Destatis, 2017).

We separately gathered this information for investments in energy saving technologies related to firms' production processes or buildings. The adoption of energy saving technologies in the production processes includes investments in motor systems and drives, thermal systems, combustion or electrical systems, or industrial design features of the production processes or operations. The adoption of technologies to increase the energy efficiency of the maintained buildings includes investments in heating or cooling systems, insulation, or lighting. We explicitly emphasized that investments in energy saving technologies do not include replacement investments. Only specific investments to improve the energy efficiency should be considered. In Table 7, we present the descriptive statistics of the investments in energy saving technologies and the additional variables used.

Credit rating — To measure the credit constraints of a firm, we use a firm-specific credit rating index provided by the rating agency Creditreform e.V. The Creditreform Solvency Index has been used as a measure for credit constraints in different empirical studies such as Hottenrott and Peters (2012). The index takes values between 100 and 600, calculated by firm-specific information, whereby 100 denotes the best rating. The calculation of the Creditreform Solvency Index involves a wide range of information relevant to a firm's solvency and performance. It can be used to forecast the probability of default and consequently a firm's credit worthiness. Attributes used to calculate the Creditreform Solvency Index include: credit verdict, mode of payment, financial report data, industry risk, regional risk, company development, and order-book situation. In total, there are 15 attributes used to calculate the index. The Creditreform Solvency Index is partly comparable to the Standards & Poors credit rating. In Table 6, we present the credit ratings of the firms for the year 2011.

Table 6: Credit Rating 2011 - descriptive statistics

Creditreform Rating	Creditreform Solvency Index	Standard & Poors credit rating	Number	Percent
I - Very good solvency	100-202	AAA - BBB	164	24
II - Good solvency	203-235	BBB - BB+	282	42
III - Satisfactory solvency	236-278	BB+ - BB	166	25
IV - Above average risk	279-298	BB - B+	36	5
V - High risk	299-349	B+ - B-	19	3
VI - Very high risk	350-600	from B-	6	1
Total			673	100

Energy management practices — To measure the energy management practices implemented by a firm, we asked the firms about three different energy management practices which firms could have implemented: 1. Regular assessment of the potential to improve energy efficiency, 2. Implementation of an energy or environmental management system,[5] and 3. Use of specific energy consumption or energy efficiency targets. This makes it possible to examine the importance of the type of energy management practice. Furthermore, we analyze the number of energy management practices implemented by every firm. We use this information as a proxy for the intensity with which firms use energy management practices.

Decision making processes — Another relevant aspect of investment decisions is the use of investment appraisal in the internal decision making process.[6] We asked the firms whether they use investment appraisal in general for their investment decisions and whether they use investment appraisal specifically to assess investments in energy saving technologies. Furthermore, we asked the firms if they use more restrictive criteria to assess investment projects related to energy saving technologies.

[5] Energy or environmental management systems are management tools to monitor and improve energy- or environment-related processes. There are different certification standards which are applicable for these management schemes: Energy management systems - DIN EN ISO 500001, DIN EN ISO 16001; Environmental management systems - DIN EN ISO 14001; EMAS I/II (Eco-Management and Audit Scheme).

[6] Investment appraisal is the planning process to determine whether investments are worth funding. There are different methods used, for example accounting rate of return, payback period, net present value, internal rate of return or real options valuation.

Energy costs and intensity — An investment in energy saving technologies may include an additional fixed cost, but could lead to reductions of a firm's variable energy costs and also of its energy intensity (Bustos, 2011). We analyze the relationship of the investments to the firm's energy intensity and define energy intensity, similar to Martin et al. (2012), as the energy cost share of turnover, also to prevent the firm size (i. e. turnover) from driving our results. We asked the firms in our survey about their energy costs and turnover in the years 2011 and 2013. In addition, we asked for the share of heating or cooling related energy costs. The composition of the energy costs could drive investments in different technologies.

Table 7: Descriptive statistics

Variables	Obs	Mean	Std. Dev.	Min	Max	P50
Investments – Production processes						
Investment decision on EST 2013	671	0.3	0.46	0	1	0
Investment volume of EST 2013 (in 1000 EUR)	198	492.02	1,815.32	1	20,000	70
Publicly subsidized loans received	685	0.09	0.29	0	1	0
Investments – Maintained buildings						
Investment decision on EST 2013	680	0.24	0.43	0	1	0
Investment volume of EST 2013 (in 1000 EUR)	162	233.75	775.91	1	8,080	50
Publicly subsidized loans received	684	0.06	0.23	0	1	0
Energy management practices						
Assessment of EE potential	701	0.72	0.45	0	1	1
Energy consumption targets	700	0.36	0.48	0	1	0
Energy management system	700	0.37	0.48	0	1	0
One energy management practice implemented	701	0.33	0.47	0	1	0
Two energy management practices implemented	701	0.24	0.43	0	1	0
Three energy management practices implemented	701	0.21	0.41	0	1	0
Internal decision making processes						
Investment appraisal - general	696	0.87	0.34	0	1	1
Investment appraisal - energy saving technologies	697	0.75	0.43	0	1	1
Investment appraisal - more restrictive criteria for EST	699	0.15	0.36	0	1	0
Energy costs						
Energy costs 2011 (in 1000 EUR)	584	2,579.85	34,061.63	0	800,000	100
Share of heating or a/c in energy costs 2011	574	0.26	0.24	0	1	0.2
Ownership of bulidings	483	0.70	0.46	0	1	1
Energy self-generation						
Energy self-generation with fossil fuels	700	0.47	0.50	0	1	0
Energy self-generation with RES	695	0.23	0.42	0	1	0

Energy self-generation — Self-generation of energy could be related to investments in energy saving technologies as discussed in our theoretical considerations above. To understand the behavior regarding energy self-generation of firms better, we asked whether the firms generate electricity or thermal energy on their own. We distinguish between the generation of energy with fossil fuels and renewable energy sources (RES). Additionally, the implementation of energy self-generation plants could also be an indication of the firms' knowledge and awareness of their energy use behavior.

It should be noted that all continuous variables in the data set are right-skewed. Thus, we use the natural logarithm of these variables in our analyses. Furthermore, we lag the explanatory variables by two years, if possible, to avoid potential simultaneity bias.

5 Empirical approach

Our goal is to better understand firms' decisions to invest in energy saving technologies. Building on the intuition developed from our theoretical decision model above, we use econometric modeling techniques in order to empirically examine the determinants of the investments for German manufacturing firms.

Our first econometric approach assumes a firm's investment decision to be a binary decision problem. The dependent variable takes the value 1 if the firm invested in energy saving technologies and 0 otherwise. Using probit and logit models, we investigate the influence of determinants, such as the firm's characteristics, on the probability of investing in energy saving technologies at all.[7] Our second econometric approach takes the censored character of the investment volume into account. In particular, we estimate two-part and selection models to understand the relationship between the decision whether to invest and how much to invest. These approaches allow us to draw conclusions on the effects of different determinants on the investment volume.

An appropriate procedure to deal with a binary dependent variable is to estimate a discrete choice probit or logit model.[8] The probit (logit) model can be generally derived from an underlying latent variable model which satisfies classical linear assumptions in addition to assuming the normal (logisitc) distributions (Wooldridge, 2002). We observe whether the firm invested in energy saving technologies or not and assume that there is an unobserved or latent variable, y_i^*, that establishes the following linear relation between the relevant variables:

$$y_i^* = \beta x_i + u_i, \tag{2}$$

where x_i is the vector of the explanatory variables, β the associated vector of the coefficients, and u_i a normal (logisitc) distributed error term with zero mean.

The observed variable y_i relates to the unobserved latent variable y_i^* as follows:

$$y_i = \begin{cases} 1 & if\ y_i^* > 0 \\ 0 & if\ y_i^* \leq 0 \end{cases} \tag{3}$$

The latent variable is the index of an unobserved propensity for the investment to occur. By combining Equation 2 and 3, the probability of firm i investing is given by

$$Prob(y_i = 1) = Prob(y_i^* > 0) = Prob(u_i > -\beta x_i) = Prob(NPV_i > 0). \tag{4}$$

In our specification this translates into the following linear relationship for the latent variable equation:

$$y_i^* = \alpha + \theta G_i + \mu M_i + \phi F_i + \chi X_i + u_i, \tag{5}$$

[7] The results of both models are very similar, theoretically as well as for our specifications (cf. Cameron and Trivedi, 2005).

[8] As a simple alternative Cameron and Trivedi (2005) suggest to employ an OLS regression of y on x. The so called Linear Probability Model (LPM) can provide a reasonable direct estimate of the sample average marginal effect on the probability that $y = 1$ as x changes, but it provides a poor model for individual probabilities and is not suitable for the purpose of prediction. Nonetheless, we apply the LPM to draw a comparison with the more appropriate probit and logit models. These results can be found in the Appendix.

where X_i is a vector including different firm characteristics. Vector G_i subsumes all variables regarding the information and knowledge barrier; this includes for our analysis energy management practices and decision making processes. M_i is a vector including the variables representing the salience and awareness variables, which subsumes energy intensity, the energy cost share of heating or cooling, energy self-generation, and in the case of investments in buildings their ownership. The financial barriers and incentives are represented by the vector F_i. We include the firms' credit rating and whether they received publicly subsidized loans as proxies in our analysis. An overview can be found in Table 2.

For the probit model we assume the standard normal cumulative distribution function $\Phi(\cdot)$ of u_i and we can rewrite Equation 4 as follows (cf. Wooldridge, 2002):

$$\begin{aligned} Prob(y_i = 1) = Prob(NPV_i > 0) = \Phi(\beta x_i) \\ = \Phi(\alpha + \theta G_i + \mu M_i + \phi F_i + \chi X_i + u_i). \end{aligned} \tag{6}$$

The variable measuring the investment volume is left censored, since firms either choose not to invest or invest a positive amount of money. The application of the OLS model does not account for the censoring and may therefore lead to inconsistent results. Consequently, we analyze the decision to invest and the amount invested in energy saving technologies using two-part and Heckman selection models.[9]

In the first part of the two-part model, the binary outcome equation is estimated using a binary outcome model like the aforementioned probit or logit model. In the second part a linear regression model is used for estimating only the positive values. The two-part model for y_i is given by:

$$f(y|x) = \begin{cases} Pr(d = 0|x) & if\ y_i = 0 \\ Pr(d = 1|x) f(y|d = 1, x) & if\ y_i > 0 \end{cases} \tag{7}$$

d denotes a binary indicator of positive investment such that $d = 1$ if $y > 0$ and $d = 0$ if $y = 0$. We only observe $Pr(d = 0)$ if $y = 0$.

The two-part model obtains some of its flexibility by assuming that the two parts are independent. But those firms with positive investments are not randomly selected from the population. Therefore, we use the selection model to allow for possible dependencies in the two parts of the model (cf. Cameron and Trivedi, 2005). The bivariate sample selection model (Heckman, 1979) comprises a selection equation for y_1, where

$$y_1 = \begin{cases} 1 & if\ y_1^* > 0 \\ 0 & if\ y_1^* \leq 0 \end{cases} \tag{8}$$

[9]Another possibility to take the left censored investment variable into account is by employing a tobit model for our analysis. The tobit model has strong assumptions. That is that the same probability mechanism generates both the zeros and the positive values, and additionally that the errors are normally distributed and homoscedastic (cf. Cameron and Trivedi, 2005). For our data the assumptions are not met, therefore we do not use the tobit model for our main analysis, but present the results in the Appendix together with the results of the OLS regressions. Despite the described shortcomings, we also estimate the OLS regression as a simple robustness check.

and a resulting outcome equation for y_2, where

$$y_2 = \begin{cases} y_2^* & if\ y_1^* > 0 \\ - & if\ y_1^* \leq 0 \end{cases} . \tag{9}$$

Here y_2 is only observed when $y_1^* > 0$. The classic model is linear with additive errors, thus

$$\begin{aligned} y_1^* &= \beta_1 x_1^{'} + \epsilon_1 \\ y_2^* &= \beta_2 x_2^{'} + \epsilon_2 \end{aligned} \tag{10}$$

with ϵ_1 and ϵ_2 possibly correlated. The difference between the two-part and Heckman selection model is the inclusion of the inverse mills ratio in the second stage of the Heckman selection model. By including this, we assume that both parts are not independent from each other.

We apply the described regression models separately for the firms' production processes and the firm's buildings in order to investigate the investment decision on energy saving technologies related to both of these categories.

6 Results

We shed light on firm characteristics as well as drivers and barriers that influence the investments in energy saving technologies. First, we describe the results for the investments in firms' production processes. Second, we show and discuss the results for the investments in firms' buildings. Finally, we check the robustness of our results.

We report our main estimation results in Tables 8 and 10 for the investments in energy saving technologies in the production processes and buildings respectively. In the tables, we show the results of the different specifications as described in Section 5.

6.1 Investments in energy saving technologies of production processes

In the year 2013, 30 percent of the firms in our sample invested in technologies to increase the energy efficiency of their production processes with a mean investment volume of 492,020 EUR.

Applying a probit model, we can identify determinants influencing the investment decision (cf. Table 8). We find that the credit rating of firms influences their decision to invest in energy saving technologies. The influence of firms' credit rating in 2011 is negatively correlated with the probability of investing in the year 2013 at the 10 percent significance level. The lower the credit rating, the higher is the propensity to invest. Keeping in mind that lower Creditreform Solvency Index scores represent better credit worthiness, this is in line with our theoretical considerations about the influence of credit constraints on the NPV of investments in energy saving technologies as well as the theoretical and empirical, self-reported, evidence from the economic literature (cf. Rohdin et al., 2007, Schleich and Gruber, 2008; Allcott and Greenstone, 2012; or Gillingham and Palmer, 2014). To identify how the probability of investing depends on

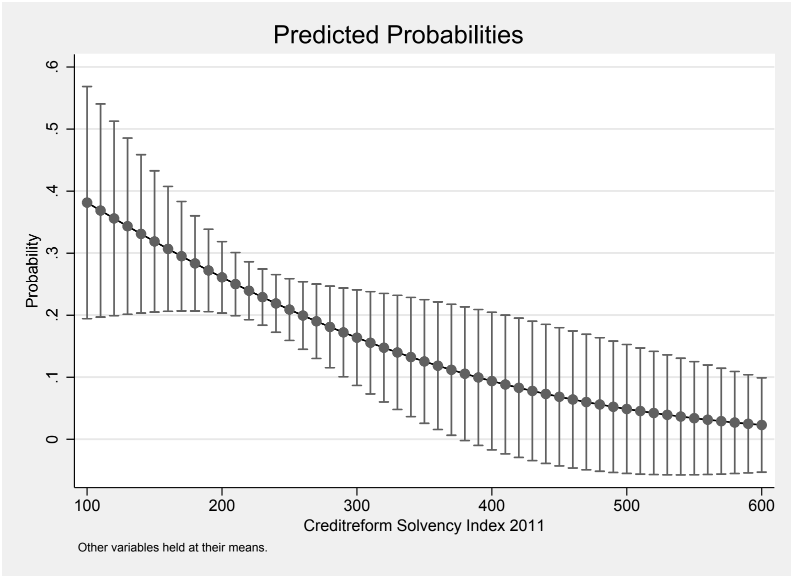
Table 8: Investments in energy saving technologies of production processes

Investment in EST of prod. proc. in 2013	Probit (Selec. Eq.) (Decision)	Two-Part (Volume>0)	Heckman (Volume>0)
Creditreform Solvency Index 2011	-0.087*	-0.160	-0.344
	(0.048)	(0.391)	(0.569)
Publicly subsidized loans received - prod. proc.		0.377	0.385
		(0.378)	(0.380)
Assessment of EE potential	-0.005	0.480	0.505
	(0.051)	(0.509)	(0.514)
Energy consumption targets	0.229***	0.758**	1.319
	(0.037)	(0.362)	(1.306)
Energy management system	0.044	-0.099	0.005
	(0.042)	(0.356)	(0.427)
Investment appraisal - energy saving technology	0.072	-0.216	-0.040
	(0.050)	(0.486)	(0.627)
ln(Energy intensity 2011)	0.094	7.869**	7.829**
	(0.235)	(3.050)	(3.066)
Share of heating or a/c in energy costs 2011	-0.191**	-0.084	-0.525
	(0.087)	(0.753)	(1.244)
Self-generation with fossil fuels	0.120***	-0.025	0.277
	(0.037)	(0.335)	(0.755)
Self-generation with RES	0.109***	0.183	0.426
	(0.041)	(0.317)	(0.631)
Exporting company in 2011	0.147***	0.312	0.629
	(0.042)	(0.420)	(0.825)
Labor intensity 2011	0.020	0.716***	0.764***
	(0.023)	(0.220)	(0.245)
ln(Age)	-0.007	0.131	0.116
	(0.025)	(0.176)	(0.180)
Location in East Germany	-0.002	-0.647	-0.653
	(0.048)	(0.392)	(0.394)
Part of a group	-0.052	0.194	0.067
	(0.051)	(0.441)	(0.526)
International location of production	-0.048	-0.072	-0.186
	(0.054)	(0.491)	(0.555)
Inverse mills ratio			0.924
			(2.066)
Sector dummies†	yes	yes	yes
Number of observations	446	124	124
Log-likelihood value	-202.75	-199.716	-199.573
R-squared		0.460	0.461
Pseudo-R-squared	0.234		

Notes: The probit model reports the average marginal effects. * p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in parentheses. †The model includes sector dummies based on the NACE two-digit industry level.

the credit rating of the firms, we calculate the predicted probabilities as a function of the credit ratings, while holding all other variables of our sample at their means. The results in Figure 1 show that the probability of investing declines substantially from 0.4 for a higher rated firm to less than 0.2 for a firm with 'above average risk' (Creditreform Rating IV, cf. Table 6) all else equal.

Figure 1: Credit constraints



Furthermore, we find a positive relationship between energy management practices and the propensity to invest in energy efficiency. Especially, the implementation of energy consumption targets has a strong positive effect on the investment probability (cf. Table 8). Also, the implementation intensity of energy management practices plays a role for the decision making (cf. Table 9). Thus, the more energy management practices are implemented by the firms, the higher is the influence on the probability of investing in the energy efficiency of the production processes. Both the average marginal effect, thus the probability, and the significance level increase when two and three energy management practices are implemented compared to the reference category, in which no energy management practices are implemented. Again, this is in line with our theoretical considerations about energy management practices: the more information and knowledge related to energy practices and processes are present in firms, the higher is the probability of investing in measures to increase the energy efficiency of the production processes. This adds to the results of Martin et al. (2012) and Boyd and Curtis (2014) that management practices do have an effect on the energy efficiency of firms. We can show that energy management practices are positively associated with the propensity to invest in energy saving technologies in order to increase the energy efficiency of the production processes.

Contrary to theoretical considerations about the behavior of energy intensive firms (cf. Schleich and Gruber, 2008), we do not find a statistically significant relationship between energy intensity and the investment decision of increasing the energy efficiency of the production processes. However, energy intensity affects the size of the investments. Apart from that, the share of heating or cooling in energy costs is correlated with the decision to invest in the energy efficiency of the production processes. The higher the cost share of heating or cooling was in 2011, the lower is the probability of investing in measures increasing the energy efficiency of firms' productions processes in 2013. Thus, firms concentrate more on investments in the energy efficiency of their production processes if they are relatively more relevant in terms of cost shares.

Self-generation of energy regardless of whether generated with fossil fuels or renewable energy sources is positively related with the investment decision. The average marginal effect of the self-generation with fossil fuels, however, is larger than the average marginal effect regarding RES. Thus, whether or not firms already generate energy plays a role in the decision making process regarding energy efficiency investments in the production processes; and if they self-generate energy with fossil fuels the probability of investing is larger than if they use renewable energy sources. The fact that firms produce energy indicates that they are aware of their energy use and consider measures to influence it. The significance of the energy management practices shown above also hints at the fact that information and knowledge about their energy use are relevant for firms.

Additionally, we find that firms' exporting status is positively correlated with the investment decision. Firms exporting in 2011 have a higher probability of investing in energy saving technologies in 2013. The literature suggests that exporting could increase energy efficiency through different channels like innovation or better management practices (Roy and Yasar, 2015). Furthermore, there is empirical literature suggesting that exporting firms have a higher productivity than non-exporting firms (e. g. Wagner, 2012). This is consistent with our finding that exporting firms invest in more energy efficient capital goods to create an overall more efficient capital stock. Other firm characteristics, like age or location, have no statistically significant influence on the investment decision. This applies also to decision making processes, more precisely the investment appraisal of energy efficiency investments.

Overall, the fully specified models, including control variables, we employ in the probit estimations have a relatively good fit as the Pseudo R^2's take the values 0.23 for the regression with the different energy management practices (cf. Table 8) and 0.22 for the regression analyzing the energy management intensity (cf. Table 9). Also the percentage of outcomes correctly predicted by the models are in a range giving the models good explanatory power for our research question. The values for the goodness of fit indicators for the other model specifications as well as the comprehensive results can be found in Table 17 in Appendix C. To test the robustness of our results with regard to the investment decision, we also apply other estimation approaches. These estimation results are presented in Appendix C. We can show that the results are robust to different specifications of the models and the different modeling strategies. The robustness checks with a logit or LPM model show similar results as the probit model, except for the Creditreform

Table 9: Investments in energy saving technologies for production processes - energy management intensity

Investment in EST of prod. proc. in 2013	Probit (Selec. eq.) (Decision)	Two-Part (Volume>0)	Heckman (Volume>0)
Creditreform Solvency Index 2011	-0.080*	-0.161	-0.319
	(0.048)	(0.395)	(0.570)
Publicly subsidized loans received - prod. proc.		0.263	0.274
		(0.375)	(0.378)
One energy management practice	-0.008	0.569	0.551
	(0.052)	(0.601)	(0.606)
Two energy management practices	0.128**	0.937	1.261
	(0.062)	(0.598)	(1.030)
Three energy management practices	0.343***	1.221**	1.869
	(0.077)	(0.600)	(1.780)
Investment appraisal - energy saving technology	0.071	-0.169	-0.010
	(0.050)	(0.496)	(0.645)
ln(Energy intensity 2011)	0.098	7.844**	7.824**
	(0.221)	(3.101)	(3.116)
Share of heating or a/c in energy costs 2011	-0.138	0.141	-0.165
	(0.089)	(0.754)	(1.096)
Self-generation with fossil fuels	0.113***	-0.037	0.235
	(0.038)	(0.340)	(0.781)
Self-generation with RES	0.094**	0.192	0.389
	(0.041)	(0.320)	(0.601)
Exporting company in 2011	0.124***	0.358	0.612
	(0.044)	(0.411)	(0.778)
Labor intensity 2011	0.012	0.610***	0.632***
	(0.023)	(0.212)	(0.220)
ln(Age)	-0.005	0.120	0.110
	(0.026)	(0.178)	(0.180)
Location in East Germany	0.002	-0.682*	-0.684*
	(0.049)	(0.405)	(0.407)
Part of a group	-0.057	0.187	0.063
	(0.053)	(0.447)	(0.552)
International location of production	-0.046	-0.022	-0.112
	(0.054)	(0.499)	(0.552)
Inverse mills ratio			0.863
			(2.233)
Sector dummies†	yes	yes	yes
Number of observations	447	124	124
Log-likelihood value	-206.54	-201.196	-201.090
R-squared		0.447	0.448
Pseudo-R-squared	0.220		

Notes: The probit model reports the average marginal effects. * p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in parentheses. †The model includes sector dummies based on the NACE two-digit industry level.

Solvency Index, which is not statistically significant in some of the specifications.

To explain also the investment volume, if firms invested in energy saving technologies for their production processes, we employ the above explained two-part and selection models.[10] The results are presented in the last two columns of Tables 8 and 9. The drivers relevant for the investment volume are energy intensity and labor intensity. Both indicators are measured in 2011 and have an influence on the investment volume in 2013. One interpretation could be that firms try to decrease their energy intensity or energy use by investing in energy efficient capital and thus substitute energy with capital. The same rationale seems to hold for labor which could also be substituted with energy efficient capital goods. Furthermore, the awareness of energy-related concerns should be higher in firms which have a higher energy intensity and thus high shares of energy costs compared to turnover.

Energy consumption targets also influence the investment volume, but this result is not robust for the selection model. If we assume that the decision to invest and the investment volume are not independent, there is no correlation between energy management practices and the investment in energy efficiency. We get the same result for the specification regarding the energy management intensity. However, we showed above that there is a strong relationship to the investment decision as such. For both models, but only in the specification of the energy management intensity (cf. Table 9), the location in Eastern Germany is negatively correlated with the investment volume.

6.2 Investments in energy saving technologies of buildings

About 25 percent of the firms in our sample invest in energy saving technologies to improve the energy efficiency of their buildings, with a mean investment volume of 233,750 EUR in 2013. The estimation results for the investment decision in energy saving technologies of buildings lead to the conclusion that energy management practices have an influence on the investment decision, cf. Tables 10 and 11. The energy efficiency investments in buildings are statistically significantly correlated with the assessment of the energy efficiency potential as well as the implementation of energy or environmental management systems, but not with the presence of energy consumption targets. The results regarding the energy management intensity are similar to the results above. If more than one energy management practice is implemented, the propensity to invest in the energy efficiency of buildings is larger. But there is no difference in the average marginal effects or significance levels regarding two or three implemented energy management practices.

The credit rating of 2011 is not statistically significantly correlated with the propensity to invest in the year 2013. Thus, we do not find firms' credit constraints to have a significant influence on the investments in the buildings they maintain, i. e. to be an investment barrier. On the other hand, we find that the use of investment appraisal to evaluate investments in the energy efficiency of their buildings has a positive statistically

[10]There is no evidence for a potential selection bias in the analysis applying the Heckman selection model, as there is no statistically significant coefficient estimated for the inverse mills ratio.

Table 10: Investments in energy saving technologies of buildings

Investment in EST of buildings in 2013	Probit (Selec. Eq.) (Decision)	Two-Part (Volume>0)	Heckman (Volume>0)
Creditreform Solvency Index 2011	-0.004	-0.311	-0.351
	(0.051)	(0.423)	(0.446)
Publicly subsidized loans received - buildings		0.458	0.465
		(0.445)	(0.448)
Assessment of EE potential	0.104**	0.268	0.798
	(0.053)	(0.493)	(1.857)
Energy consumption targets	0.053	-0.222	0.056
	(0.042)	(0.365)	(1.010)
Energy management system	0.081*	0.123	0.501
	(0.045)	(0.398)	(1.338)
Investment appraisal - energy saving technology	0.121**	0.587	1.209
	(0.054)	(0.535)	(2.170)
ln(Energy intensity 2011)	-0.466	-0.285	-2.607
	(0.385)	(3.272)	(8.509)
Share of heating or a/c in energy costs 2011	0.196**	-1.472*	-0.546
	(0.083)	(0.791)	(3.228)
Self-generation with fossil fuels	0.053	0.353	0.623
	(0.039)	(0.358)	(0.980)
Self-generation with RES	0.137***	0.558*	1.200
	(0.041)	(0.328)	(2.197)
Exporting company in 2011	0.045	0.011	0.221
	(0.045)	(0.431)	(0.832)
Labor intensity 2011	0.007	0.286	0.317
	(0.027)	(0.225)	(0.249)
ln(Age)	-0.002	-0.026	-0.044
	(0.024)	(0.213)	(0.222)
Location in East Germany	-0.002	-0.163	-0.171
	(0.050)	(0.433)	(0.437)
Part of a group	-0.044	0.584	0.349
	(0.056)	(0.539)	(0.962)
International location of production	0.032	0.501	0.683
	(0.059)	(0.546)	(0.825)
Inverse mills ratio			1.884
			(6.366)
Sector dummies†	yes	yes	yes
Number of observations	454	111	111
Log-likelihood value	-219.08	-176.471	-176.404
R-squared		0.448	0.449
Pseudo-R-squared	0.140		

Notes: The probit model reports the average marginal effects. * p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in parentheses. †The model includes sector dummies based on the NACE two-digit industry level.

significant correlation with the investment decision. Thus, for the investments in the energy efficiency of buildings, more structured approaches, including for example internal rate of return calculations, are important.

Energy costs also influence the decision to invest in the energy efficiency of buildings. Particularly, the share of heating or cooling in the energy costs in 2011 is positively correlated with the propensity to invest in 2013. The higher the share in energy costs is, the higher is the probability of investing in energy efficiency measures. The result is in line with the influence of the energy cost share on the decision to invest in the energy efficiency of the production processes. This suggests that firms concentrate their investments in those areas that contribute more to their overall energy costs.

As pointed out in Section 2, increasing the energy efficiency of buildings and simultaneously the use of renewable energy sources is a possibility to reduce greenhouse gas emissions. Our results regarding the investments in the energy efficiency of firms' buildings hint at the fact that firms implementing one of the two measures are more likely to implement the other measure as well. Thus, the self-generation of energy with renewable energy sources is statistically significantly correlated with the decision to invest in the energy efficiency of buildings.

The relevant drivers of the volume invested in the energy saving technologies of buildings are analyzed with the help of two-part and Heckman selection models. Drivers with a statistically significant relationship are the energy cost share of heating or cooling and the self-generation with RES. Counterintuitively, the energy cost share is negatively correlated with the investment volume. However, the result is not robust as no significant effect is found in the Heckman selection model. The positive effect associated with self-generation with RES is also not robust for the specification in the Heckman selection model.

When investments in the energy efficiency of buildings are discussed, one of the most widely named sources of the energy efficiency gap is the principal-agent conflict. It can arise due to different incentives for owners and renters, in this case, of buildings (Gerarden et al., 2017; Gillingham and Palmer, 2014). This issue has mostly been analyzed for residential buildings, e. g. Gillingham et al. (2012). We investigate this issue for firms, i. e. whether the ownership of buildings is related with firms' investment behavior.

We do not find evidence for the importance of split incentives for investments in energy saving technologies in firms' buildings (cf. Table 12). This result is in line with the results of Hochman and Timilsina (2017) for Ukrainian commercial and industrial firms. We find a significant influence of the ownership status on the investment decision in our basic model, but this result is not robust if we include control variables in our fully specified estimation models.[11] These fully specified models have a much better

[11] One could argue that some of our independent variables are highly correlated to the ownership of the buildings like energy self-generation. This could lead to the problem of multicollinearity. In Table 25 in Appendix E, we show the Pearson correlation coefficients between the ownership of buildings and selected variables. We do not find strong correlations between these factors; the maximal correlation value is below 0.14. In conclusion, a distortion by multicollinearity seems not relevant for our analysis.

Table 11: Investments in energy saving technologies of buildings - energy management index

Investment in EST of buildings in 2013	Probit (Selec. eq.) (Decision)	Two-Part (Volume>0)	Heckman (Volume>0)
Creditreform Solvency Index 2011	-0.005	-0.335	-0.385
	(0.052)	(0.425)	(0.450)
Publicly subsidized loans received - buildings		0.401	0.403
		(0.455)	(0.458)
One energy management practice	0.048	0.120	0.419
	(0.048)	(0.593)	(1.043)
Two energy management practices	0.199***	0.279	1.275
	(0.060)	(0.575)	(2.910)
Three energy management practices	0.199***	0.027	1.044
	(0.068)	(0.629)	(2.979)
Investment appraisal - energy saving technology	0.126**	0.614	1.274
	(0.053)	(0.530)	(1.962)
ln(Energy intensity 2011)	-0.454	0.257	-2.027
	(0.362)	(3.293)	(7.331)
Share of heating or a/c in energy costs 2011	0.186**	-1.630**	-0.763
	(0.083)	(0.795)	(2.609)
Self-generation with fossil fuels	0.054	0.350	0.628
	(0.038)	(0.359)	(0.875)
Self-generation with RES	0.136***	0.573*	1.231
	(0.041)	(0.330)	(1.914)
Exporting company in 2011	0.048	0.032	0.265
	(0.045)	(0.435)	(0.799)
Labor intensity 2011	0.009	0.299	0.340
	(0.026)	(0.219)	(0.249)
ln(Age)	-0.000	-0.031	-0.039
	(0.024)	(0.212)	(0.215)
Location in East Germany	0.007	-0.188	-0.148
	(0.050)	(0.425)	(0.443)
Part of a group	-0.052	0.638	0.350
	(0.055)	(0.527)	(0.980)
International location of production	0.034	0.492	0.697
	(0.058)	(0.545)	(0.804)
Inverse mills ratio			1.908
			(5.461)
Sector dummies†	yes	yes	yes
Number of observations	455	111	111
Log-likelihood value	-218.29	-176.579	-176.486
R-squared		0.447	0.448
Pseudo-R-squared	0.144		

Notes: The probit model reports the average marginal effects. * p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in parentheses. †The model includes sector dummies based on the NACE two-digit industry level.

Table 12: Investments in energy saving technologies and ownership of buildings

Investment in EST of buildings in 2013	Probit (Selc. Eq. / decision)			Two-part (volume>0)		
	I	II	III	I	II	III
Ownership of buldings	0.113**	0.042	0.052	0.436	0.362	0.510
	(0.044)	(0.054)	(0.053)	(0.304)	(0.582)	(0.614)
Creditreform Solvency Index 2011		-0.043	-0.040		-0.281	-0.445
		(0.058)	(0.058)		(0.430)	(0.489)
Assessment of EE potential		0.100			0.627	
		(0.062)			(0.647)	
Energy consumption targets		0.079			0.238	
		(0.049)			(0.516)	
Energy management system		0.133**			-0.612	
		(0.056)			(0.554)	
One energy management practice			0.025			-0.127
			(0.052)			(0.856)
Two energy management practices			0.241***			0.152
			(0.077)			(0.595)
Three energy management practices			0.268***			-0.106
			(0.080)			(0.680)
Investment appraisal - energy saving technology		0.136**	0.133**		0.071	0.371
		(0.065)	(0.064)		(0.548)	(0.534)
ln(Energy intensity 2011)		-0.407	-0.354		2.082	1.609
		(0.451)	(0.451)		(2.669)	(2.866)
Share of heating and a/c in energy costs 2011		0.205**	0.199**		-3.055***	-2.904***
		(0.101)	(0.100)		(0.976)	(0.919)
Self generation with fossil fuels		0.084*	0.079		0.269	0.307
		(0.048)	(0.048)		(0.502)	(0.585)
Self generation with RES		0.166***	0.162***		0.373	0.482
		(0.047)	(0.046)		(0.399)	(0.390)
Exporting company in 2011		0.041	0.042		-0.061	-0.148
		(0.052)	(0.052)		(0.541)	(0.559)
Labor intensity 2011		0.014	0.019		0.463	0.318
		(0.031)	(0.031)		(0.305)	(0.298)
ln(Age)		-0.015	-0.015		0.046	0.032
		(0.029)	(0.029)		(0.232)	(0.235)
Location in East Germany		-0.009	-0.000		0.399	0.212
		(0.057)	(0.057)		(0.603)	(0.569)
Part of a group		-0.088	-0.090		0.680	0.501
		(0.072)	(0.069)		(0.562)	(0.709)
International location of production		0.055	0.063		0.799	0.932
		(0.070)	(0.067)		(0.553)	(0.680)
Publicly subsidized loans received - buildings					0.784	0.650
					(0.594)	(0.552)
Sector dummies†		yes	yes		yes	yes
Number of observations	470	315	315	114	81	81
R-squared				0.013	0.583	0.562
Pseudo-R-squared	0.013	0.198	0.206			
Percent correctly predicted	75.74	80.63	80.95			
Log-likelihood value	-257.102	-144.818	-143.426	-213.353	-113.900	-115.852

Notes: * p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in parentheses. †The model includes sector dummies based on the NACE two-digit industry level. The probit models report the average marginal effects.

fit (Pseudo R^2: 0.198 and 0.206) than models which only take the ownership without control variables into account (Pseudo R^2: 0.013). Additionally, we do not find significant results in any specification for the investment volume when the firms decided to invest, incorporating a two-part model.

6.3 Robustness of the results: Bivariate probit regression

The previous results explaining the investment decision on energy saving technologies by firms are based on the assumption that the investment decisions for production processes and buildings are independent. However, these decisions could respond to common factors and the internal decision process for investments in a firm should include the consideration of all investment decision types together. To incorporate these insights in our analysis, we provide results from the estimation with a bivariate probit regression model to analyze possible correlations of the latent variables (Cameron and Trivedi, 2005). To implement this, we use the same specifications as in the probit model estimations above, but allow the errors to be correlated across equations. We present the results in Table 13. The results including the number of energy management practices implemented (intensity) can be found in Appendix F.

The results of the estimations show that we can reject the null hypothesis of no correlation. That is, using the bivariate probit model is appropriate. The comparison with the results of the single variate probit models, however, shows no significant differences in the results. Thus, the coefficients are in general comparable in their size and sign. In addition, the significance levels are also comparable to the ones in the separate estimations.

Table 13: Bivariate probit model

	Probit model		Bivariate probit model	
Investment in EST in 2013	prod. proc.	buildings	prod. proc.	buildings
Creditreform Solvency Index 2011	-0.339*	-0.014	-0.314*	-0.033
	(0.189)	(0.189)	(0.183)	(0.189)
Assessment of EE potential	-0.020	0.382**	-0.036	0.362*
	(0.201)	(0.194)	(0.200)	(0.192)
Energy consumption targets	0.898***	0.194	0.910***	0.188
	(0.160)	(0.155)	(0.160)	(0.157)
Energy management system	0.174	0.299*	0.160	0.284*
	(0.166)	(0.167)	(0.167)	(0.170)
Investment appraisal - energy saving technology	0.283	0.444**	0.279	0.462**
	(0.197)	(0.201)	(0.196)	(0.202)
ln(Energy intensity 2011)	0.368	-1.716	0.384	-1.621
	(0.919)	(1.419)	(0.923)	(1.496)
Share of heating or a/c in energy costs 2011	-0.748**	0.724**	-0.807**	0.726**
	(0.345)	(0.311)	(0.346)	(0.315)
Self-generation with fossil fuels	0.468***	0.195	0.469***	0.228
	(0.150)	(0.143)	(0.150)	(0.145)
Self-generation with RES	0.424**	0.504***	0.434***	0.503***
	(0.165)	(0.156)	(0.166)	(0.156)
Exporting company in 2011	0.575***	0.167	0.583***	0.174
	(0.170)	(0.168)	(0.172)	(0.168)
Labor intensity 2011	0.079	0.027	0.067	0.017
	(0.091)	(0.098)	(0.090)	(0.099)
ln(Age)	-0.028	-0.006	-0.028	-0.006
	(0.098)	(0.088)	(0.096)	(0.087)
Location in East Germany	-0.007	-0.009	0.014	-0.062
	(0.188)	(0.186)	(0.187)	(0.188)
Part of a group	-0.204	-0.163	-0.183	-0.186
	(0.202)	(0.206)	(0.198)	(0.206)
International location of production	-0.189	0.117	-0.209	0.072
	(0.211)	(0.217)	(0.208)	(0.222)
Constant	-1.565	-2.099	-1.464	-1.981
	(1.279)	(1.360)	(1.261)	(1.371)
Rho			0.403***	
			(0.101)	
Sector dummies†	yes	yes	yes	yes
Number of observations	446	454	450	
Percent correctly predicted	78.7	79.1		
Log-likelihood value	-202.75	-219.08	-411.40	
Pseudo-R-squared	0.234	0.140		

Notes: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. Robust standard errors in parentheses. †The model includes sector dummies based on the NACE two-digit industry level.

7 Concluding remarks

We investigate the determinants of firms' decisions to invest in energy saving technologies to increase the energy efficiency of their production processes as well as the buildings they maintain. Furthermore, we analyze the determinants of the volume of these investments of German manufacturing firms. To this goal, we employ different estimation models either analyzing the decision and volume independently or simultaneously. We focus especially on the relationships regarding credit constraints and energy management practices. The increase in energy efficiency is one of the main goals of current energy and climates policies. Therefore, it is crucial to identify important drivers of investments in the energy efficiency of firms to assist decision makers in implementing effective management tools. Moreover, it is essential to aid policy makers in providing efficient policy instruments.

Our results suggest that there is a positive relationship between credit ratings and the investment decision in energy saving technologies to increase the energy efficiency of firms' production processes. The better the firm's credit rating, the higher is the probability of investing in energy saving technologies. Thus, credit constraints seem to be a barrier to these investments. There are already subsidized loan programs in place to support firms' investments in energy efficiency and lower financial barriers; however, these could be adjusted according to the insights we have presented. If policy makers want to increase the number of firms investing in energy efficiency and achieving the overarching energy efficiency targets, it could be, for example, feasible to adjust the requirements for loans and thus provide better incentives to firms to invest in energy efficiency.

For the influence of energy management practices on investments in the energy efficiency of production processes, we can summarize our findings as follows: Energy management practices play a significant role both for the investment decision and in the simultaneous analyses of investment decision and volume. The most important management practice is the implementation of energy consumption targets by firms, but as our analysis of the intensity of the implemented energy management practices shows this should not be the only energy management practice. If there are two or more practices implemented the probability of investing in energy efficiency is higher than with only one or no energy management practice installed. On the other hand, energy management practices do not or only weakly explain the volume invested by these firms. Thus, to increase the number of firms which invest in energy saving technologies, programs promoting energy management practices seem to be a feasible instrument, but note that our study is not an evaluation of a specific program.

Further drivers are the energy intensity and cost shares of heating or cooling of the firms. Thus, if energy costs are a more important cost component, the probabilities of investing and the volume tend to be higher, too. Firms generating their own energy are also more likely to invest in energy saving technologies.

The investments in energy saving technologies increasing the energy efficiency of buildings do not depend on the firms' credit ratings. Thus, the drivers differ from those of the production processes. Nonetheless, the positive correlation with the presence of energy management practices also holds for the investments in the energy efficiency of the maintained buildings. For buildings, the important management practices are the assessment of the energy efficiency potential and energy management systems. Here, the intensity of implemented energy management practices also is an important driver. Again two and more practices increase significantly the probability to invest compared to one or none implemented management practice. Policies should therefore focus on a mixture of measures to implement different energy management practices, to increase awareness about energy efficiency and the information and knowledge of energy use related topics.

Structured internal decision making processes as a management tool also play a significant role for investment decisions regarding the energy efficiency of buildings. On the other hand, the principal-agent problem often considered a barrier to energy efficiency enhancements of buildings does not play a significant role in the investment behavior of the firms in our analysis. Furthermore, the cost share of heating plays a significant role; thus to decrease energy costs firms invest in energy efficiency. Self-generation with renewable energy sources is connected to an increase in energy efficiency, which also reflects the combination of these two topics in policy measures regarding the energy efficiency of buildings.

Comparing the heterogeneous results for the different investment categories (production processes and buildings), we can conclude that analyses of investments in energy saving technologies should take this heterogeneity into account. This insight should also influence the discussion about and implementation of tailored policy instruments for the different investment categories. Future research could include a more detailed ex-post evaluation of the causal effects of policy instruments regarding energy efficiency improvements, a deeper analysis of firm performance indicators, or other relevant drivers. Furthermore, administrative data regarding energy efficiency investments and therefore a bigger sample size could be an interesting extension to our insights in future research.

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Appendix

A German energy efficiency policies in force in 2013

Table 14: Energy efficiency policies - Production processes

Policy measure	Year	Policy type
Directive to stimulate energy efficient and climate friendly production processes	2013	Direct investment, Funds, Economic Instruments
Directive to stimulate energy management systems	2013	Standard, Fiscal/financial incentives
KfW Special Fund for Energy Efficiency in SMEs	2013	Information and education, Economic Instruments
Financial support for investments in cross sectional technology	2012	Grants and subsidies, Information and education
SME Initiative for the Energy Transition	2012	Information and education
Energy consulting in SMEs	2012	Information and education, Fiscal/financial incentives
CHP Agreements with Industry	2012	Negotiated agreement
Energy Efficiency Fund	2011	Financial incentives
Energy-related Products Act (EVPG): Implementing measure for electrical appliances	2009	Standard
Energy-related Products Act (EVPG): Ecodesign implementing measure for electric motors	2009	Standard
Green IT Initiative of the federal government	2008	Information and education
Stimulus Programme for Mini CHP Plants	2008	Financial incentives
Special Fund for Energy Efficiency in SMEs	2008	Loans, Information and education
Smart Energy Efficiency and Climate Protection Networks	2008	Information and education
BAFA On-site Consultation	1998	Fiscal/financial incentives
Small-Scale Combustion Plant Ordinance	1996	Standard
Energy Consumption Labelling Ordinance (EnVKV)		Information and education, Energy labeling
Environment Innovation Programme		Fiscal/financial incentives

Notes: Excerpt of IEA Policy and Measures Database: Energy Efficiency by selection of "Policy Targets": "Commercial/Industrial equipment"; "Industry"; "Multi-Sectoral Policy,Industry". Source: IEA (2017).

Table 15: Energy efficiency policies - Buildings

Policy measure	Year	Policy type
SME Initiative for the Energy Transition	2012	Information and education
Energy consulting in SMEs	2012	Information and education, Fiscal/financial incentives
Heating Cost Ordinance	2009	Standard
Low-energy building in the building stock	2003	Information and education
Energy Saving Act (EnEG)/Energy Saving Ordinance (EnEV)	2002	Codes and standards
Energy Conservation Ordinance	2002	Codes and standards
The Guide to Sustainable Construction	2001	Information and education
KfW CO2 Building Redevelopment Programme	2001	Fiscal/financial incentives
Energy certificate	1995	Codes and standards, Information and education
Federal states' activities in the buildings sector	1995	Fiscal/financial incentives

Notes: Excerpt of IEA Policy and Measures Database: Energy Efficiency by selection of "Policy Targets": "Buildings"; "Buildings, Industry"; "Buildings>BuildingType>Non-residential". Sources: BMWi (2017) and IEA (2017).

B Sample Selection

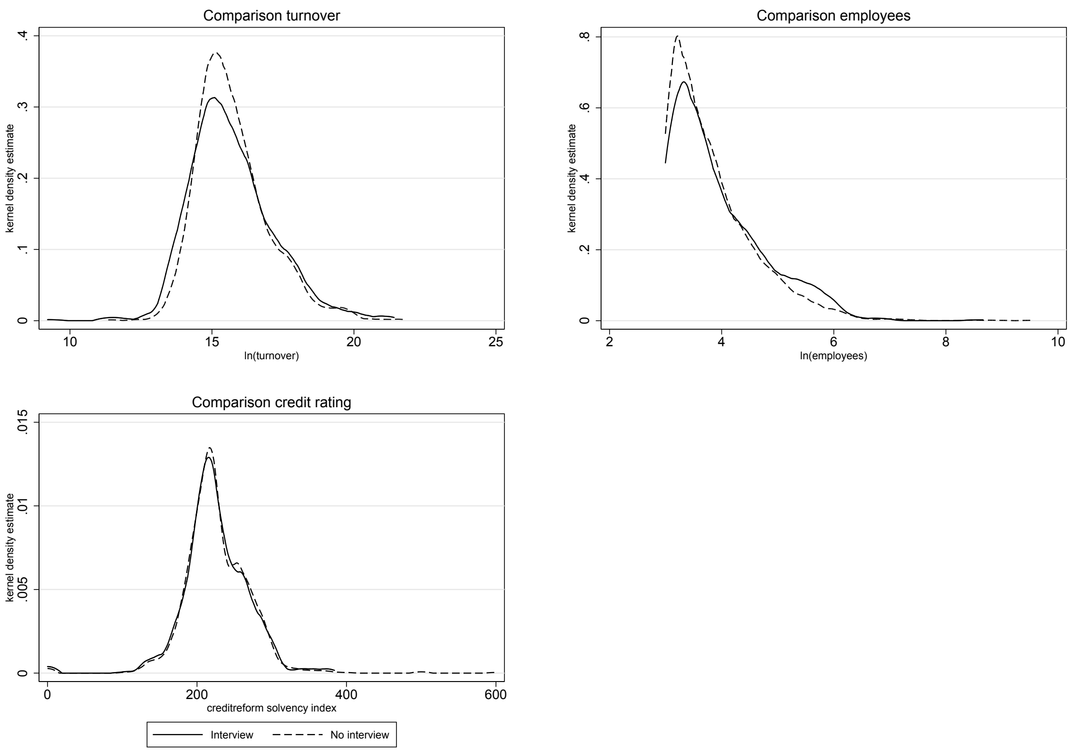
Although we contacted firms randomly, selection bias can arise as an issue, if there are systematic differences between responding and non-responding firms. We are able to show whether there is selection in terms of the variables we observe for non-respondents and respondents. Therefore, we regress the following firm characteristics available from the MUP data set (i. e. turnover, employees, and credit rating) on a dummy variable indicating whether a firm was contacted and on sector dummies. The estimated coefficients reported in Table 16 are small and statistically insignificant. Also the graphical comparison with the help of kernel density plots, presented in Figure 2, shows no significant differences for the aforementioned firm characteristics. To conclude, we can assume randomness for our sample selection procedure.

Table 16: Representativeness of interviewed firms

Variable	Turnover 2011	Employees 2011	Creditreform Solvency Index 2011
Firm granted interview	-0.060	-0.730	-1.499
	(0.054)	(12.306)	(1.921)
R-squared	0.057	0.011	0.019
Number of observations	3095	3187	3194

Notes: Each column shows the results from an OLS regression of the MUP variable given in the column head on a dummy variable indicating whether an interview was granted or not. All regressions include industry dummies based on the NACE two-digit industry level. Robust standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

Figure 2: Representativeness of interviewed firms - Graphical analysis



C Robustness check: Investments in energy saving technologies of production processes

Table 17: Investment decision - Comparison of probit models

	Probit model					
Investment in EST of prod. proc. in 2013	I	II	III	IV	V	VI
Creditreform Solvency Index 2011	-0.095**				-0.087*	-0.080*
	(0.046)				(0.048)	(0.048)
Assessment of EE potential		0.151***			-0.005	
		(0.041)			(0.051)	
Energy consumption targets		0.199***			0.229***	
		(0.033)			(0.037)	
Energy management system		0.124***			0.044	
		(0.034)			(0.042)	
One energy management practice			0.078**			-0.008
			(0.036)			(0.052)
Two energy management practices			0.261***			0.128**
			(0.045)			(0.062)
Three energy management practices			0.506***			0.343***
			(0.048)			(0.077)
Investment appraisal - energy saving technologies				0.213***	0.072	0.071
				(0.042)	(0.050)	(0.050)
ln(Energy intensity 2011)					0.094	0.098
					(0.235)	(0.221)
Share of heating or a/c in energy costs 2011					-0.191**	-0.138
					(0.087)	(0.089)
Self-generation with fossil fuels					0.120***	0.113***
					(0.037)	(0.038)
Self-generation with RES					0.109***	0.094**
					(0.041)	(0.041)
Exporting company in 2011					0.147***	0.124***
					(0.042)	(0.044)
Labor intensity 2011					0.020	0.012
					(0.023)	(0.023)
ln(Age)					-0.007	-0.005
					(0.025)	(0.026)
Location in East Germany					-0.002	0.002
					(0.048)	(0.049)
Part of a group					-0.052	-0.057
					(0.051)	(0.053)
International location of production					-0.048	-0.046
					(0.054)	(0.054)
Sector dummies†					yes	yes
Number of observations	655	669	671	668	446	447
Percent correctly predicted	70.5	74.9	75.0	70.4	78.7	79.0
Log-likelihood value	-394.95	-351.21	-352.03	-393.18	-202.75	-206.54
Pseudo-R-squared	0.005	0.136	0.135	0.032	0.234	0.220

Notes: The probit models report the average marginal effects. * p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in parentheses. †The model includes sector dummies based on the NACE two-digit industry level.

Table 18: Investment decision - Model comparison

Investment in EST of prod. proc. in 2013	Probit model	Logit model	LPM model	Probit model	Logit model	LPM model
Creditreform Solvency Index 2011	-0.087*	-0.088*	-0.079	-0.080*	-0.082	-0.073
	(0.048)	(0.048)	(0.051)	(0.048)	(0.050)	(0.051)
Assessment of EE potential	-0.005	-0.002	-0.007			
	(0.051)	(0.056)	(0.047)			
Energy consumption targets	0.229***	0.227***	0.272***			
	(0.037)	(0.036)	(0.049)			
Energy management system	0.044	0.041	0.070			
	(0.042)	(0.042)	(0.051)			
One energy management practice				-0.008	-0.012	-0.018
				(0.052)	(0.056)	(0.049)
Two energy management practices				0.128**	0.126*	0.127**
				(0.062)	(0.065)	(0.063)
Three energy management practices				0.343***	0.333***	0.365***
				(0.077)	(0.077)	(0.074)
Investment appraisal - energy saving technologies	0.072	0.069	0.065	0.071	0.070	0.061
	(0.050)	(0.053)	(0.045)	(0.050)	(0.052)	(0.043)
ln(Energy intensity 2011)	0.094	0.102	0.109	0.098	0.113	0.115
	(0.235)	(0.212)	(0.304)	(0.221)	(0.198)	(0.264)
Share of heating or a/c in energy costs 2011	-0.191**	-0.195**	-0.184**	-0.138	-0.151*	-0.136
	(0.087)	(0.088)	(0.082)	(0.089)	(0.092)	(0.084)
Self-generation with fossil fuels	0.120***	0.122***	0.119***	0.113***	0.116***	0.112***
	(0.037)	(0.038)	(0.043)	(0.038)	(0.038)	(0.043)
Self-generation with RES	0.109***	0.114***	0.111**	0.094**	0.099**	0.099**
	(0.041)	(0.041)	(0.049)	(0.041)	(0.041)	(0.049)
Exporting company in 2011	0.147***	0.144***	0.146***	0.124***	0.126***	0.121***
	(0.042)	(0.043)	(0.044)	(0.044)	(0.045)	(0.045)
Labor intensity 2011	0.020	0.021	0.018	0.012	0.012	0.011
	(0.023)	(0.024)	(0.024)	(0.023)	(0.023)	(0.025)
ln(Age)	-0.007	-0.008	-0.011	-0.005	-0.006	-0.006
	(0.025)	(0.025)	(0.028)	(0.026)	(0.026)	(0.028)
Location in East Germany	-0.002	0.004	0.014	0.002	0.006	0.011
	(0.048)	(0.049)	(0.051)	(0.049)	(0.051)	(0.051)
Part of a group	-0.052	-0.053	-0.071	-0.057	-0.061	-0.071
	(0.051)	(0.053)	(0.057)	(0.053)	(0.055)	(0.057)
International location of production	-0.048	-0.049	-0.043	-0.046	-0.043	-0.042
	(0.054)	(0.053)	(0.060)	(0.054)	(0.053)	(0.059)
Sector dummies†	yes	yes	yes	yes	yes	yes
Number of observations	446	446	450	447	447	451
Percent correctly predicted	78.7	78.9		79.0	79.0	
Log-likelihood value	-202.75	-202.40	-209.97	-206.54	-206.36	-212.69
R-squared			0.258			0.249
Pseudo-R-squared	0.234	0.235		0.220	0.221	

Notes: The probit and logit models report the average marginal effects. * p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in parentheses. †The model includes sector dummies based on the NACE two-digit industry level.

C.1 Robustness check: Tobit model

The tobit model can be derived from an underlying latent variable model which satisfies classical linear assumptions and assumes a normal distribution (Wooldridge, 2002). The observed variable y_i relates in this case to the unobserved latent variable y_i^* as follows:

$$y_i = \begin{cases} y_i^* & if\ y_i^* > 0 \\ 0 & if\ y_i^* \leq 0 \end{cases} \tag{11}$$

Consistent estimates using a tobit model require homoscedasticity and normality of the residuals. Our models fail both tests, which are suggested by Cameron and Trivedi (2005). Thus, heteroscedasticity is present. We could control for this. But the bigger problem is the finding from the Lagrange multiplier test that also normality of the residuals must be strongly rejected. In this sense, the tobit model should actually not be applied. Therefore, we also report the results of the OLS estimation. Note that the simple and linear OLS model provides fairly similar results compared to the tobit model.

Moreover, the OLS model allows to handle heteroscedasticity much more easily than the non-linear model.

The tobit models, which we estimate with the same specifications as the probit models, give insights not only regarding the investment decision but also the amount the firms invested if they invested. As shown in Table 19, the results are fairly similar to the results for the probit model. By comparison of the joint log likelihood of the two-part models (-402.47 and -407.74), selection models (-402.32 and -407.63), and the log likelihood of the tobit models (-605.01 and -609.16), the two-part and selection models fit our data better than the tobit model.

Table 19: Investment volume - Comparison of tobit models

	Tobit model					
ln(Investment in EST of prod.proc. 2013)	I	II	III	IV	V	VI
Creditreform Solvency Index 2011	-1.215**				-0.778*	-0.730
	(0.569)				(0.456)	(0.469)
Assessment of EE potential		1.954***			0.068	
		(0.504)			(0.540)	
Energy consumption targets		2.336***			2.326***	
		(0.390)			(0.395)	
Energy management system		1.512***			0.407	
		(0.402)			(0.414)	
One energy management practice			0.749**			-0.006
			(0.331)			(0.419)
Two energy management practices			2.890***			1.301**
			(0.503)			(0.564)
Three energy management practices			6.395***			3.769***
			(0.597)			(0.824)
Investment appraisal - energy saving technologies				2.717***	0.721	0.744
				(0.532)	(0.527)	(0.529)
ln(Energy intensity 2011)					0.868	0.782
					(2.359)	(2.223)
Share of heating or a/c in energy costs 2011					-1.883**	-1.382
					(0.842)	(0.876)
Self-generation with fossil fuels					1.241***	1.210***
					(0.372)	(0.381)
Self-generation with RES					1.008***	0.897**
					(0.386)	(0.394)
Exporting company in 2011					1.443***	1.256***
					(0.437)	(0.455)
Labor intensity 2011					0.271	0.181
					(0.229)	(0.229)
ln(Age)					-0.045	-0.032
					(0.243)	(0.252)
Location in East Germany					-0.149	-0.109
					(0.447)	(0.465)
Part of a group					-0.430	-0.485
					(0.489)	(0.510)
International location of production					-0.552	-0.525
					(0.509)	(0.521)
Sector dummies†					yes	yes
Number of observations	655	669	671	668	450	451
Log-likelihood value	-1020.96	-989.12	-990.22	-1035.23	-605.01	-609.16
Pseudo-R-squared	0.002	0.057	0.057	0.013	0.099	0.093

Notes: The tobit model reports marginal effects on the latent variable mean. * p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in parentheses. †The model includes sector dummies based on the NACE two-digit industry level.

Table 20: Investment volume - Model Comparison

ln(Investment in EST of prod.proc. 2013)	Tobit model	OLS model	Tobit model	OLS model
Creditreform Solvency Index 2011	-0.778*	-0.934	-0.730	-0.867
	(0.456)	(0.585)	(0.469)	(0.581)
Assessment of EE potential	0.068	0.021		
	(0.540)	(0.498)		
Energy consumption targets	2.326***	3.169***		
	(0.395)	(0.548)		
Energy management system	0.407	0.812		
	(0.414)	(0.576)		
One energy management practice			-0.006	-0.153
			(0.419)	(0.505)
Two energy management practices			1.301**	1.422**
			(0.564)	(0.665)
Three energy management practices			3.769***	4.402***
			(0.824)	(0.818)
Investment appraisal - energy saving technologies	0.721	0.591	0.744	0.574
	(0.527)	(0.486)	(0.529)	(0.461)
ln(Energy intensity 2011)	0.868	2.880	0.782	2.980
	(2.359)	(4.200)	(2.223)	(3.637)
Share of heating or a/c in energy costs 2011	-1.883**	-2.222**	-1.382	-1.652*
	(0.842)	(0.927)	(0.876)	(0.937)
Self-generation with fossil fuels	1.241***	1.293***	1.210***	1.217**
	(0.372)	(0.477)	(0.381)	(0.476)
Self-generation with RES	1.008***	1.328**	0.897**	1.200**
	(0.386)	(0.563)	(0.394)	(0.564)
Exporting company in 2011	1.443***	1.701***	1.256***	1.399***
	(0.437)	(0.492)	(0.455)	(0.510)
Labor intensity 2011	0.271	0.345	0.181	0.257
	(0.229)	(0.283)	(0.229)	(0.285)
ln(Age)	-0.045	-0.086	-0.032	-0.037
	(0.243)	(0.323)	(0.252)	(0.325)
Location in East Germany	-0.149	-0.036	-0.109	-0.082
	(0.447)	(0.549)	(0.465)	(0.552)
Part of a group	-0.430	-0.723	-0.485	-0.731
	(0.489)	(0.651)	(0.510)	(0.655)
International location of production	-0.552	-0.408	-0.525	-0.404
	(0.509)	(0.697)	(0.521)	(0.686)
Sector dummies†	yes	yes	yes	yes
Number of observations	450	450	451	451
Log-likelihood value	-605.01	-1298.08	-609.16	-1302.47
R-squared		0.281		0.276
Pseudo-R-squared	0.099		0.093	

Notes: The tobit model reports marginal effects on the latent variable mean. * p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in parentheses. †The model includes sector dummies based on the NACE two-digit industry level.

D Robustness check: Investments in energy saving technologies of buildings

Table 21: Investment decision - Comparison of probit models

	Probit model					
Investment in EST of buildings in 2013	I	II	III	IV	V	VI
Creditreform Solvency Index 2011	-0.084*				-0.004	-0.005
	(0.045)				(0.051)	(0.052)
Assessment of EE potential		0.170***			0.104**	
		(0.040)			(0.053)	
Energy consumption targets		0.069**			0.053	
		(0.035)			(0.042)	
Energy management system		0.067*			0.081*	
		(0.035)			(0.045)	
One energy management practice			0.083**			0.048
			(0.036)			(0.048)
Two energy management practices			0.192***			0.199***
			(0.044)			(0.060)
Three energy management practices			0.284***			0.199***
			(0.048)			(0.068)
Investment appraisal - energy saving technologies				0.239***	0.121**	0.126**
				(0.042)	(0.054)	(0.053)
ln(Energy intensity 2011)					-0.466	-0.454
					(0.385)	(0.362)
Share of heating or a/c in energy costs 2011					0.196**	0.186**
					(0.083)	(0.083)
Self-generation with fossil fuels					0.053	0.054
					(0.039)	(0.038)
Self-generation with RES					0.137***	0.136***
					(0.041)	(0.041)
Exporting company in 2011					0.045	0.048
					(0.045)	(0.045)
Labor intensity 2011					0.007	0.009
					(0.027)	(0.026)
ln(Age)					-0.002	-0.000
					(0.024)	(0.024)
Location in East Germany					-0.002	0.007
					(0.050)	(0.050)
Part of a group					-0.044	-0.052
					(0.056)	(0.055)
International location of production					0.032	0.034
					(0.059)	(0.058)
Sector dummies†					yes	yes
Number of observations	664	678	680	677	454	455
Percent correctly predicted	75.9	76.1	76.2	76.1	79.1	78.5
Log-likelihood value	-364.66	-351.21	-353.61	-355.50	-219.08	-218.29
Pseudo-R-squared	0.005	0.058	0.053	0.046	0.140	0.144

Notes: The probit models report the average marginal effects. * p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in parentheses. †The model includes sector dummies based on the NACE two-digit industry level.

Table 22: Investment decision - Model comparison

Investment in EST of buildings in 2013	Probit model	Logit model	LPM model	Probit model	Logit model	LPM model
Creditreform Solvency Index 2011	-0.004	-0.013	-0.008	-0.005	-0.016	-0.012
	(0.051)	(0.053)	(0.057)	(0.052)	(0.053)	(0.057)
Assessment of EE potential	0.104**	0.103*	0.078			
	(0.053)	(0.056)	(0.048)			
Energy consumption targets	0.053	0.057	0.066			
	(0.042)	(0.042)	(0.048)			
Energy management system	0.081*	0.078*	0.091*			
	(0.045)	(0.046)	(0.051)			
One energy management practice				0.048	0.045	0.029
				(0.048)	(0.050)	(0.051)
Two energy management practices				0.199***	0.196***	0.189***
				(0.060)	(0.062)	(0.062)
Three energy management practices				0.199***	0.198***	0.195***
				(0.068)	(0.070)	(0.075)
Investment appraisal - energy saving technologies	0.121**	0.122**	0.098**	0.126**	0.126**	0.103**
	(0.054)	(0.059)	(0.047)	(0.053)	(0.058)	(0.047)
ln(Energy intensity 2011)	-0.466	-0.441	-0.353	-0.454	-0.422	-0.374
	(0.385)	(0.403)	(0.233)	(0.362)	(0.384)	(0.234)
Share of heating or a/c in energy costs 2011	0.196**	0.201**	0.195**	0.186**	0.191**	0.187**
	(0.083)	(0.084)	(0.091)	(0.083)	(0.085)	(0.090)
Self-generation with fossil fuels	0.053	0.056	0.053	0.054	0.057	0.055
	(0.039)	(0.039)	(0.043)	(0.038)	(0.039)	(0.042)
Self-generation with RES	0.137***	0.135***	0.153***	0.136***	0.135***	0.151***
	(0.041)	(0.040)	(0.053)	(0.041)	(0.040)	(0.052)
Exporting company in 2011	0.045	0.042	0.037	0.048	0.046	0.039
	(0.045)	(0.047)	(0.046)	(0.045)	(0.047)	(0.046)
Labor intensity 2011	0.007	0.011	0.007	0.009	0.012	0.009
	(0.027)	(0.028)	(0.028)	(0.026)	(0.028)	(0.028)
ln(Age)	-0.002	-0.005	-0.003	-0.000	-0.003	-0.001
	(0.024)	(0.024)	(0.026)	(0.024)	(0.024)	(0.026)
Location in East Germany	-0.002	-0.003	-0.011	0.007	0.009	-0.000
	(0.050)	(0.051)	(0.054)	(0.050)	(0.051)	(0.054)
Part of a group	-0.044	-0.046	-0.045	-0.052	-0.053	-0.054
	(0.056)	(0.057)	(0.060)	(0.055)	(0.056)	(0.059)
International location of production	0.032	0.030	0.029	0.034	0.033	0.030
	(0.059)	(0.059)	(0.070)	(0.058)	(0.058)	(0.069)
Sector dummies†	yes	yes	yes	yes	yes	yes
Number of observations	454	454	455	455	455	456
Percent correctly predicted	79.1	79.1		78.5	78.5	
Log-likelihood value	-219.08	-219.10	-228.92	-218.29	-218.23	-227.69
R-squared			0.142			0.147
Pseudo-R-squared	0.140	0.140		0.144	0.144	

Notes: The probit and logit models report the average marginal effects. * p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in parentheses. †The model includes sector dummies based on the NACE two-digit industry level.

D.1 Robustness check: Tobit model

The estimations with the tobit model, to take also the investment volume into account, show results similar to our estimations with probit models. These are presented in Table 23. But the same results for the Lagrange multiplier test as for the tobit models for the production processes hold for the estimations regarding the maintained buildings. The consistent estimates using a tobit model would require homoscedasticity and normality of the residuals. The specification fails both tests. Thus, heteroscedasticity is present and normality of the residuals must be strongly rejected. We therefore also implement and report the OLS estimation results in Table 24. The OLS model also provides fairly similar results compared to the tobit and probit model. We extend our analysis with the use of two-part and selection models. The model fit is better than the one of the tobit models, if we compare the log likelihood values of the estimations (Tobit: -580.57 and -580.11; Two-part: -395.55 and -394.87; Heckman: -395.48 and -394.78).

Table 23: Investment volume - Comparison of tobit models

	Tobit model					
ln(Investment in EST of buildings 2013)	I	II	III	IV	V	VI
Creditreform Solvency Index 2011	-0.997*				-0.035	-0.061
	(0.514)				(0.514)	(0.523)
Assessment of EE potential		1.980***			1.131**	
		(0.455)			(0.549)	
Energy consumption targets		0.750**			0.482	
		(0.379)			(0.410)	
Energy management system		0.807**			0.805*	
		(0.382)			(0.441)	
One energy management practice			0.845**			0.466
			(0.359)			(0.416)
Two energy management practices			2.126***			1.950***
			(0.482)			(0.596)
Three energy management practices			3.339***			2.022***
			(0.562)			(0.708)
Investment appraisal - energy saving technologies				2.820***	1.283**	1.349**
				(0.464)	(0.568)	(0.560)
ln(Energy intensity 2011)					-4.573	-4.413
					(3.671)	(3.512)
Share of heating or a/c in energy costs 2011					1.752**	1.605**
					(0.805)	(0.804)
Self-generation with fossil fuels					0.551	0.561
					(0.384)	(0.382)
Self-generation with RES					1.343***	1.346***
					(0.401)	(0.398)
Exporting company in 2011					0.427	0.463
					(0.460)	(0.457)
Labor intensity 2011					0.090	0.105
					(0.261)	(0.260)
ln(Age)					-0.013	-0.004
					(0.233)	(0.234)
Location in East Germany					-0.044	0.033
					(0.501)	(0.497)
Part of a group					-0.382	-0.451
					(0.575)	(0.563)
International location of production					0.432	0.463
					(0.598)	(0.589)
Sector dummies†					yes	yes
Number of observations	664	678	680	677	455	456
Log-likelihood value	-880.29	-871.90	-874.51	-876.31	-580.57	-580.11
Pseudo-R-squared	0.002	0.026	0.024	0.021	0.060	0.062
Controls†					yes	yes

Notes: The tobit model reports marginal effects on the latent variable mean. * $p<0.10$, ** $p<0.05$, *** $p<0.01$. Robust standard errors in parentheses. †The model includes sector dummies based on the NACE two-digit industry level.

Table 24: Investment volume - Model Comparison

ln(Investment in EST of buildings 2013)	Tobit model	OLS model	Tobit model	OLS model
Creditreform Solvency Index 2011	-0.035	-0.175	-0.061	-0.208
	(0.514)	(0.625)	(0.523)	(0.627)
Assessment of EE potential	1.131**	0.861*		
	(0.549)	(0.510)		
Energy consumption targets	0.482	0.675		
	(0.410)	(0.532)		
Energy management system	0.805*	1.016*		
	(0.441)	(0.564)		
One energy management practice			0.466	0.349
			(0.416)	(0.533)
Two energy management practices			1.950***	2.002***
			(0.596)	(0.667)
Three energy management practices			2.022***	2.144***
			(0.708)	(0.818)
Investment appraisal - energy saving technologies	1.283**	1.084**	1.349**	1.148**
	(0.568)	(0.498)	(0.560)	(0.493)
ln(Energy intensity 2011)	-4.573	-3.112	-4.413	-3.326
	(3.671)	(2.541)	(3.512)	(2.589)
Share of heating or a/c in energy costs 2011	1.752**	1.805*	1.605**	1.703*
	(0.805)	(1.005)	(0.804)	(0.996)
Self-generation with fossil fuels	0.551	0.604	0.561	0.629
	(0.384)	(0.470)	(0.382)	(0.467)
Self-generation with RES	1.343***	1.750***	1.346***	1.737***
	(0.401)	(0.585)	(0.398)	(0.581)
Exporting company in 2011	0.427	0.305	0.463	0.328
	(0.460)	(0.507)	(0.457)	(0.506)
Labor intensity 2011	0.090	0.183	0.105	0.203
	(0.261)	(0.305)	(0.260)	(0.309)
ln(Age)	-0.013	-0.045	-0.004	-0.026
	(0.233)	(0.282)	(0.234)	(0.281)
Location in East Germany	-0.044	-0.190	0.033	-0.083
	(0.501)	(0.580)	(0.497)	(0.577)
Part of a group	-0.382	-0.275	-0.451	-0.361
	(0.575)	(0.664)	(0.563)	(0.656)
International location of production	0.432	0.459	0.463	0.463
	(0.598)	(0.775)	(0.589)	(0.765)
Sector dummies†	yes	yes	yes	yes
Number of observations	455	455	456	456
Log-likelihood value	-580.57	-1314.02	-580.11	-1315.51
R-squared		0.150		0.154
Pseudo-R-squared	0.060		0.062	

Notes: The tobit model reports marginal effects on the latent variable mean. * p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in parentheses. †The model includes sector dummies based on the NACE two-digit industry level.

E Ownership of buildings and multicollinearity

Table 25: Ownership of buildings and multicollinearity

	Full sample†		Restricted sample‡	
Ownership of buildings	Pearson correlation coefficients	Obs	Pearson correlation coefficients	Obs
ln(energy intensity)	0.0209	394	0.0037	315
Energy self-generation with fossil fuels	0.1171	483	0.1092	315
Energy self-generation with RES	0.1372	478	0.1256	315
Share of heating or a/c in energy cost	-0.1071	395	-0.0729	315

Notes: † Number of observations varies because of data availability. ‡ Sample used in probit model II in Table 12.

F Robustness check: Bivariate probit model

Table 26: Bivariate probit model – energy management intensity

	Probit model		**Bivariate probit model**	
Investment in EST in 2013	prod. proc.	buildings	prod. proc.	buildings
Creditreform Solvency Index 2011	-0.310*	-0.019	-0.292	-0.036
	(0.188)	(0.192)	(0.182)	(0.192)
One energy management practice	-0.036	0.215	-0.053	0.189
	(0.230)	(0.221)	(0.230)	(0.218)
Two energy management practices	0.468**	0.740***	0.456*	0.705***
	(0.233)	(0.235)	(0.233)	(0.231)
Three energy management practices	1.097***	0.740***	1.088***	0.703***
	(0.252)	(0.257)	(0.252)	(0.253)
Investment appraisal - energy saving technology	0.273	0.467**	0.271	0.486**
	(0.193)	(0.199)	(0.192)	(0.200)
ln(Energy intensity 2011)	0.378	-1.680	0.380	-1.534
	(0.853)	(1.342)	(0.862)	(1.376)
Share of heating or a/c in energy costs 2011	-0.531	0.689**	-0.571	0.692**
	(0.349)	(0.311)	(0.353)	(0.314)
Self-generation with fossil fuels	0.437***	0.201	0.433***	0.231
	(0.148)	(0.143)	(0.149)	(0.144)
Self-generation with RES	0.363**	0.505***	0.370**	0.503***
	(0.162)	(0.156)	(0.163)	(0.156)
Exporting company in 2011	0.478***	0.180	0.477***	0.182
	(0.172)	(0.168)	(0.173)	(0.169)
Labor intensity 2011	0.047	0.033	0.034	0.025
	(0.089)	(0.098)	(0.089)	(0.099)
ln(Age)	-0.018	-0.001	-0.020	0.001
	(0.099)	(0.089)	(0.098)	(0.089)
Location in East Germany	0.010	0.026	0.031	-0.026
	(0.188)	(0.186)	(0.186)	(0.191)
Part of a group	-0.221	-0.194	-0.206	-0.216
	(0.204)	(0.203)	(0.201)	(0.203)
International location of production	-0.176	0.127	-0.185	0.084
	(0.207)	(0.215)	(0.203)	(0.219)
Constant	-1.211	-2.127	-1.070	-2.031
	(1.256)	(1.375)	(1.242)	(1.380)
Rho			0.379***	
			(0.098)	
Number of observations	447	455	451	
Percent correctly predicted	79.0	78.5		
Log-likelihood value	-206.54	-218.29	-414.99	
Pseudo-R-squared	0.220	0.144		

Notes: * p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in parentheses. The model includes sector dummies based on the NACE two-digit industry level.