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Which firms benefit from investments in green energy technologies? – The effect of energy costs

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Abstract:

Firms will invest in green energy technologies only if these investments have an economic pay-off. Based on unique firm-level data from Austria, Germany, and Switzerland, we find that the marginal effect of investments in green energy technologies on productivity is positive only for the 19% of firms with the highest energy costs. These results have major implications for companies and policy makers regarding the design of green energy policies and incentives.

Keywords: Energy technologies; green innovation; energy costs; energy input; firm productivity.

JEL classification: O30; O34; Q55.

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1 Introduction

Though green technologies are expected to have great potential (Ambec & Lanoie 2008; King & Lenox 2002; Kunapatarawong & Martínez-Ros 2016), the diffusion of these technologies across firms remains low (Arvanitis et al. 2016). In the literature, this phenomenon is called an "efficiency gap" or "energy paradox" and is generally driven by institutional, market-related, organizational and behavioral barriers (Jaffe & Stavins 1994; Weber 1997). Porter and van der Linde (1995) state that companies are inexperienced in measuring their discharges, in understanding the full costs of incomplete utilization of resources and toxicity, and in conceiving new approaches to minimizing discharges or eliminating hazardous substances. In the end, the low diffusion of green technologies is often interpreted as evidence that managers systematically overlook profit opportunities (Majumdar & Marcus 2001; McWilliams & Siegel 2001).

The focus of this study is on companies' use of *green energy technology*, a term we define as (a) energy-saving technology used within a firm in one of the following fields: production, ICT, transport or building technology;[1] and (b) technology for the use of energy from renewable sources in the company, such as wind or hydroelectric power plants or solar systems.[2] Like green technologies as a whole, the diffusion of such green energy technologies has so far been relatively low. As described in more detail in Section 3, investments in green energy technologies in the period 2012 to 2014 amounted to, on average, 6.2% of total gross investment expenditure in Germany, 5.3% in Austria and 2.7% in Switzerland for all companies. This makes it all the more important to better understand the drivers of these adoption activities.

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[1] The survey also included an open question where companies could add other energy-saving technologies (see Table 1). However, since this question was rarely answered and the answers did not allow for specific categorization, the chosen categorization that differentiates between production, ICT, transport and building technology seems complete.

[2] Arvanitis and Ley (2013) and Stucki and Woerter (2016, 2018) use related definitions of green energy technologies. However, most studies in this field use less broad definitions and focus, for example, on technologies for the generation of energy from renewable sources (e.g., Jacobsson & Lauber 2006). To determine whether the aggregation of individual technologies causes important information to be lost, we test if our results differ across the different fields of investments by estimating our main model separately for the different fields of green technology adoption (see Table A.7 in the Appendix).

In principle, we expect that the more energy a company consumes, the greater the potential for energy inefficiency. The reduction of such energy inefficiency is an important reason for the use of green energy technologies. We therefore expect the economic returns to investment in green energy technologies to increase with the firms' energy costs. Accordingly, the impact of adopting green energy technologies on production output, in this study measured by firm productivity, should be conditional on the level of the companies' energy costs. Because we control in our econometric model in detail for the firms' industry affiliation, we use within-industry variation to identify this effect.

The number of companies with high energy costs is relatively small. According to UNIDO (2010), energy costs account for approximately 10–20% of the total production cost of industry's physical output worldwide. Energy costs are even lower in Western countries in which energy-intensive basic material producers typically make up small shares of total production (EIA 2016). Most firms are thus unlikely to show major energy inefficiencies. Accordingly, economic returns to investments in green energy technologies should be low for average (energy-intensive) companies and only positive for firms with high energy costs.[3] Hence, it may not be a systematic overlooking of profit opportunities by managers that hampers the diffusion of these green energy technologies, but instead the low energy costs of the firms.

The basis for this study is the literature examining the productivity effects of adopting green technology (Arvanitis et al. 2017; Hottenrott et al. 2016; Rexhäuser & Rammer 2014; Van Leeuven & Mohnen 2015).[4] This literature usually focuses on the direct effects of adoption, but to better understand why the diffusion of green technologies is so difficult, indirect effects of adoption – the effect of adoption via so-called moderator variables – must also be investigated (Dixon-Fowler et al.

[3] It should be noted that it can be worthwhile for a company to invest in green energy technologies despite its low energy costs. For example, this may be due to regulations or government incentives. In our empirical model, however, we try to control such factors.

[4] Several studies analyzed the effect of pollution reduction on a firm's financial performance (e.g., Hart & Ahuja 1996 for large U.S. manufacturing firms; King & Lenox 2002 for publicly traded U.S. manufacturing firms; Ruggiero & Lehkonen 2016 for large electric utilities from 26 countries). Pollution reduction, however, is typically an outcome of green investments (Lanoie et al. 2011). In contrast to these studies, we directly focus on the firms' green investments, which allows us to identify the firms' economic returns to investments. Moreover, several studies exist that analyze the productivity effects of green product innovation itself rather than the adoption of these technologies (e.g., Marin 2014; Soltmann et al. 2015).

2013; King & Lenox 2001). In this study, we focus on the moderating effect of the energy costs of companies. Although there is literature which finds evidence that energy input is an important (direct) driver of economic growth (Apergis & Payne 2009; Stern 2011; Stern & Kander 2012), its potential role as moderator of the effect of adoption of green technologies on economic outcome has not been explicitly tested so far.

To analyze the relationship between energy costs, investments in green energy technologies and productivity, we make use of a unique firm-level data set that is based on samples from Germany, Austria and Switzerland. Previous studies in this field of research have often drawn on non-random samples such as large energy firms (Ruggiero & Lehkonen 2016) or firms that issued IPOs (Hart & Ahuja 1996; King & Lenox 2002). In comparison, the sample used in this study is representative of the firm population of each of the three countries, which allows us to draw conclusions for the whole population of firms. Along with information on the firms' gross investment expenditures on green energy technologies and the firms' energy costs, the data set includes information on the firms' value added and the common drivers of firm productivity. This information allows us to base our analysis on a solid productivity model. Finally, the data set also enables the comparison of our findings across the three countries, which is important because the characteristics of the environment (e.g., the firms' affinity for green technologies) may also affect the results. If the findings are robust for all three countries, it would be evidence that the findings can be generalized to other countries as well.

The economic findings confirm the expected moderating effect of energy costs. Firms with relatively high energy costs show significantly larger marginal effects of investments in green energy technologies on productivity than do firms with relatively low energy costs. Significantly positive productivity effects from the adoption of green energy technologies are observed only for the 19% of firms with the highest energy costs.

2 Conceptual framework

Managers have long regarded pollution reduction as a threat which reduces a firm's competitiveness. Yet in recent decades this view has been criticized by a number of scholars. Porter and van der Linde

(1995) argued that pollution is often associated with a waste of resources, but should instead be seen as a sign of inefficiency within manufacturing processes (see also Hart & Ahuja 1996). A more efficient use of environmental resources means a better utilization of inputs, which may also improve a firm's economic performance (Majumdar & Marcus 2001).

According to the resource-based view (RBV), a direct link is assumed between a firm's sustained competitive advantage and its valuable, rare, imperfectly imitable, and non-sustainable resources and capabilities, such as management skills, organizational processes and routines, and the information and knowledge it controls (Barney 1991; Barney et al. 2001). As an extension to the RBV, the theory of the natural-resource-based view (NRBV) was developed (Hart 1995; Rugman & Verbeke 1998). The NRBV extends the RBV by developing a theory of how a firm's green activity can lead to a sustained competitive advantage. Such green activities lead to the development of capabilities that have implications for a firm's competitive advantage in terms of lower costs, improved reputation, and strategic alignment with future changes in the general business environment (Aragón-Correa & Sharma 2003).

Despite the substantial amount of theoretical literature that analyzes potential channels through which green activity may stimulate a firm's economic performance (see, e.g., Ambec & Lanoie 2008 for a review of this literature), it remains unclear under what conditions green activity serves as a resource for improving competitive advantage. In other words, *when* does it pay to be green (Dixon-Fowler et al. 2013; King & Lenox 2001)? This paper contributes to the discussion on when it pays to be green, with a focus on green energy technologies. We argue that the economic returns to investments for green energy technologies depend heavily on firms' energy costs (see Figure 1).

Insert Figure 1 about here

Astrov et al. (2015) provides an overview of energy cost shares, that is, the size of energy costs in percentage of gross output, across countries, industries and time periods. Energy cost shares for the whole economy in 2011 stood at 4.6% in the EU-27, at 5.1% in Japan, at 4.6% in the US and at 7.7% in China. Energy cost shares in Western countries are therefore, as expected, lower. Differences can be observed between countries as well as between industries. In 2011, energy cost shares in the EU-27 stood between slightly above 1% in transport equipment, electrical and optical equipment and machinery and about 7% in chemicals and other non-metallic mineral products. Industrial manufacture of coke, refined petroleum and nuclear fuels had a much higher energy cost share of 62%. Due to rising energy prices, energy cost shares were on the rise over time. Considering all industries, energy cost shares increased by 1.6 percentage points (pps) in the EU-27 between 1995 and 2011, by 2.3 pps in Japan, by 1.8 pps in the US and by 2.5 pps in China.[5]

2.1 Green energy investments vis-à-vis energy costs

Investments in green energy technologies can stimulate firms' economic performance through two channels: (1) by increasing revenues, and (2) by reducing costs (Ambec & Lanoie 2008). The firms' energy costs should strengthen both of them. A firm can, for example, increase its revenues if better environmental performance improves its image and prestige, and thereby increase the loyalty of customers or attract new ones (Hess et al. 1999). Such gains should be larger for firms with high energy costs. Firms with high energy costs are likely to attract more media attention (Bansel 2005) and to face greater pressure from governmental authorities, NGOs, and customers (Berrone & Gomez-Mejia 2009). This typically results in the potential for greater gains in organizational legitimacy through environmental performance (Dixon-Fowler et al. 2013), and should also increase a firm's economic returns to investments in green technologies.

Beyond the potential to increase revenues, investments in green energy technologies may also benefit the firm through lower input costs (King & Lenox 2002; Majumdar & Marcus 2001). Pollution is a manifestation of economic waste and involves inefficient use of resources (Porter & van der Linde 1995). Green energy technologies offer profit-oriented firms incentives to reduce such inefficiencies, which should lead to a reduction of input costs (Arvanitis et al. 2017; Cao & Karplus 2014).[6] Again,

[5] In the data set used in this study, the share of energy costs in sales on average of all firms amounted to 1.3% in Germany, 2.7% in Austria, and 1.4% in Switzerland in 2014 (Arvanitis et al. 2016).

[6] Regarding our definition of green energy technologies, it could be argued here that the cost effect in particular applies to energy-saving technologies, but less to technologies for the generation of energy from renewable sources. Separate

the potential for such cost reductions should increase with the firms' energy costs. Consider the example of trying to reduce the energy consumption of a (low energy-intensive) bank and a (high energy-intensive) cement producer. A bank can install sensors that turn off lights when not in use, use more energy-efficient light bulbs, or replace older data servers with newer energy-efficient models. Further reductions in energy consumption, such as changing the heating system of their office buildings and adding more insulation, would cost much more. The bank's options to significantly reduce input costs through investments in green energy technologies are limited.

In comparison, most of the bank's options are also available to the cement producer. Yet the cement producer can also save a significant amount of energy by using more energy-efficient mills for meal grinding, improving the combustion system, improving the process control and management system, or most importantly, by using blended cement (Worell et al. 2000). In sum, we thus expect that the cement producer has more options to significantly reduce input costs through investments in green energy technologies.

The above example was a simple illustration using companies from different industries. In our econometric model, however, we control in detail for the firms' industry affiliation. This means we compare the effect of firms' green investments with different levels of energy costs within the same industry, which is more like comparing a low energy-intensive bank/cement producer with a high energy-intensive bank/cement producer.[7] The idea, however, remains the same: we expect that firms with higher energy costs have more options to significantly reduce input costs through investments in green energy technologies.

Both channels indicate that marginal economic returns to investments in green energy technologies are significantly larger for firms with relatively high energy costs than for firms with relatively low energy costs. The firms' possibilities to make investments in green energy technologies

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estimates for the different types of green energy technologies show that the results hardly differ between the different types (see Table A.7 in the Appendix). This indicates that the cost channel also plays a certain role for technologies that generate energy from renewable sources. However, because our empirical framework does not allow a separation of the two channels, we cannot completely rule out the possibility that the effect of investments in technologies for energy generation from renewable sources is primarily driven by an intensified revenue channel.

[7] The data indicate that firms' energy costs vary substantially within different industries, which should allow us to identify the expected effects even when controlling for the industry affiliation of the firms (see Table A.4 in the Appendix).

with high economic returns relative to costs, to pick the so-called low-hanging fruits, should increase with the firms' energy costs.

In a related strand of the literature which focuses on different stages of pollution prevention, Hart (1995) argues that there are many such low-hanging fruits in the *early stages* of pollution prevention. With increasing environmental performance, additional reductions in emissions become progressively more difficult, often requiring significant changes in processes or even entirely new production technology (for a similar argumentation based on emission abatement costs, see Narain & van't Velt 2008 and Popp 2011). If we expect that firms with high energy costs tend to be at the early stage of pollution prevention, this argumentation supports our prediction that the firms' possibilities to pick low-hanging fruits increase with the firms' energy costs.

2.2 Direction of the net-effect of green energy investments

Whether the total economic returns to green energy investments are positive or negative is not a priori clear and is a question that must be answered empirically (Berchicci & King 2007). Yet existing empirical results are mixed. Using German firm-level data on the adoption of environmental technology, Hottenrott et al. (2016) found that the sole adoption of green technologies is associated with lower productivity. However, no significant productivity effects were observed for firms that adopt green technologies alongside changes to their organizational structure. For Germany, Rexhäuser and Rammer (2014) found that innovations that increase a firm's resource efficiency in terms of material or energy consumption per unit of output have a positive impact on profitability; green innovations which do not improve firms' resource efficiency do not provide significant economic returns. Based on a related sample, Ghisetti and Rennings (2014) found negative returns for innovations aimed at reducing externalities. Using a panel of Dutch manufacturing firm-level data, Van Leeuwen and Mohnen (2017) found that resource-saving eco-innovations, which can be assimilated into process-integrated eco-innovations, increased firm productivity. Finally, a positive effect of the adoption of green energy technologies on firm productivity was observed in Arvanitis et al. (2017) in a sample of German, Austrian, and Swiss firms.

In our study, the direction of the effect of investments in green energy technologies on economic outcome depends on how a firm's options for investments with large economic returns relative to costs –a firm's options to pick low-hanging fruits – change along with the firm's energy costs. If only firms with high energy costs can pick such low-hanging fruits, economic returns to investments in green energy technologies would be positive for firms with high energy costs, but insignificant or even negative for firms with low energy costs (scenario 1). If firms with high energy costs can pick more low-hanging fruits, while some of them can be picked by firms with low energy costs as well, positive economic returns are expected for both. According to our first prediction (see Section 2.1), the positive returns, however, should be larger for firms with high energy costs (scenario 2). If both can pick only a few low-hanging fruits, economic returns may even be negative for those firms with low energy costs as well as those with high ones (scenario 3).

Scenario 1 is probably the most realistic scenario for Western countries. The energy costs of most companies are so low that even for companies with medium energy costs, the costs play little role. As described in scenario 1, it should be difficult for most companies to find options for highly profitable investments in green energy technologies. In sum, we expect that, at least in Western countries, it is unlikely that investments to improve energy efficiency or to generate energy from renewable sources have a sufficiently strong effect to stimulate the overall productivity of firms with low or even medium energy costs. By this reasoning, only firms with the highest energy costs should be able to achieve positive economic returns to investments in green energy technologies.

3 Data

The empirical testing of the predicted relationship is based on firm-level data that were collected in the course of a survey on the "creation and adoption of energy related technologies" carried out in Austria, Germany, and Switzerland in 2015.[8] Hence, the study is based on cross-sectional data referring to the year 2014. However, since most quantitative variables contain information for 2012

[8] This is a well-established data set that has been used, for example, in Arvanitis et al. (2017), Stucki et al. (2018), Woerter et al. (2017), and Rammer et al. (2017) to analyze the effect of different environmental policy measures on the adoption and generation of green energy technologies.

and 2014, it is still possible to model certain dynamics. The survey was carried out in Switzerland by the Swiss Economic Institute (KOF), in Germany by the Center for European Studies (ZEW) and in Austria by the Austrian Institute of Economic Research (WIFO). To ensure comparability of the data, the same questionnaires were used in all three countries. To obtain representative results, the survey was based on firm samples that are representative of the firm population of each of the three countries: the WIFO Enterprise Panel for Austria, the ZEW Enterprise Panel for Germany and the KOF Enterprise Panel for Switzerland. All these samples are stratified at the two-digit industry level and at three industry-specific firm size classes (with full coverage of large firms). Concretely, the survey was sent to 6,374 German firms, 7,091 Austrian firms, and 5,789 Swiss firms. Completed surveys were received from 2,321 German firms (response rate: 36.4%), 539 Austrian firms (7.6%), and 1,815 Swiss firms (31.4%). Given the very demanding questionnaire, the response rates for Germany and Switzerland were satisfying, but disappointing for Austria. However, extensive reminder actions in all three countries, in which many of the non-responders were contacted, ensured that a sufficiently large number of answers was received for all three counties, covering all industries and all firm size classes according to the underlying sampling schemes (see Arvanitis et al. 2016 for more detailed information on the composition of the data sets and the responses received for the three countries).

In addition to questions on some basic firm characteristics (sales, exports, employment, investment and employees' education), the survey included questions on activities related to energy adoption and product innovation as well as on the firms' energy costs. The information on green energy adoption activities is based on questions that directly asked about the firms' newly adopted green energy technologies (see Table 1).[9] To properly address green energy technologies, a clear definition encompassing the following aspects was used: (a) energy-saving technology used within the firm in one of the following fields: production, ICT, transport or building technology; and (b) technologies for the use of energy from renewable sources in the company, such as wind or

[9] One advantage of this method of data collection (compared to, e.g., patent statistics) is that it allows us to distinguish directly between the adoption and the creation of such technologies. See Community Innovation Survey (CIS) for a related procedure for innovation activities in general.

hydroelectric power plants or solar systems.[10] Because firms invest irregularly in green energy technologies, investments in green energy technologies were measured as an average over the period from 2012 to 2014. In this period, 40.1% of the German firms adopted at least one green energy technology, compared to 31.9% of the Austrian firms, and 25.1% of the Swiss firms (see Table A.2 in the Appendix for information on the proportion of companies investing in green energy technologies by field and industry).[11] Of all firms with green energy adoption activities, investment in green energy technologies amounted to, on average, 17.7% of total gross investment expenditures in Germany, 19.7% in Austria, and 12.9% in Switzerland. However, due to the rather low number of firms with green energy adoption activities, these shares, when considering all of the firms, decreased to 6.2% in Germany, 5.3% in Austria, and 2.7% in Switzerland. Accordingly, the potential for increasing adoption activities remains considerable in all three countries. All the more so since green energy technologies are defined broadly to include energy saving technologies and technologies for the generation of energy from renewable sources. As expected, energy costs were relatively low for most companies in the three countries. The share of energy costs in sales on average of all firms amounted to 1.3% in Germany, 2.7% in Austria, and 1.4% in Switzerland.

Insert Table 1 about here

Some of the questionnaires were not completely filled out, which is why our final data set contains missing values for certain variables. Due to missing values for some model variables, our final estimation sample includes 4,420 observations: 49% of them are German firms, 11% Austrian firms, and 40% Swiss firms. On average, the firms in our estimation sample have 281 employees (median: 40 employees), and 88% of them are small and medium-sized enterprises with less than 250 employees. Of the firms, 51% belong to the manufacturing sector, 44% to the service sector and 5% to the construction sector.

[10] However, because only 22.4% of the firms with green energy technology adoption activity invested in energy-generating technologies from renewable sources (see Table A.2 in the Appendix), our measure for green energy technologies primarily reflects the adoption of energy-saving technology.

[11] To obtain representative information, all figures on the firms' adoption behavior and energy costs presented in this section are based on data that were weighted according to the sampling schemes of the three countries.

In our econometric model, the measures for energy costs and green investment intensity are normalized with the total number of employees engaged (L), which probably makes the measures less intuitive, but ensures that both sides of the equation are divided by L (see Section 4). Descriptive information indicates that both variables have enough variation to identify potential effects (Energy_Costs/L: p25: 870 euro; p50: 2,193 euro; p75: 5,096 euro;[12] Green_Investment/L: p25: 0 euro; p50: 0 euro; p75: 359 euro).[13]

4 Empirical testing

To test our predictions empirically, we start with a production function. Logs are taken to convert the production function to a linear model and produce an estimable equation (Hall et al. 2010; van Leeuwen & Mohnen 2017). The output is measured as value added, which is defined as sales minus purchasing costs (Value_Added). Production input includes the firms' energy input proxied by energy costs (Energy_Costs)[14], and the firms' gross investment expenditures for green energy technologies (Green_Investment):

$$\ln(Value\_Added) = \alpha \ln(Energy\_Costs) + \beta \ln(Green\_Investments) + \gamma \ln(Non\_Green\_Investments) + \delta \ln(R\&D\_Expenditures) + \rho \ln(L) + \mu + \varphi + \varepsilon. \quad (1)$$

To properly identify the effect of green investments, the equation includes controls for other standard factors of a production function such as labor input proxied by the total number of employees engaged (L), non-green capital input proxied by the firms' non-green gross investment expenditure (Non_Green_Investment), and knowledge input measured by the firms' total R&D expenditures (R&D_Expenditures).[15] Ideally, data on the capital stock should be used instead of capital formation. However, because we use a flow variable to proxy the firms' adoption of green energy technologies,

[12] See Table A.4 in the Appendix for more information on the variance in the firms' energy costs across and within industry.
[13] See Tables A.2 and A.3 in the Appendix for more information on the variance in the firms' investments in green energy technologies across and within industry, respectively.
[14] In the literature, a measure of physical quantity of energy is often used to measure energy input (e.g., Cao & Karplus 2014). However, while most of these studies focus on the macro level, it is much more difficult to construct such measures at the firm level. The survey used for this study focused on energy costs, because this is a more directly observable variable for companies and could be directly surveyed. Moreover, the use of energy costs also makes sense from a conceptual point of view, since other production inputs also flow into the production function as costs.
[15] More control variables are tested in the robustness section.

it also seems appropriate to use a flow variable to control for the effect of non-green investments. Finally, we control for the firms' industry affiliation at the NACE two-digit level (μ), and the firms' country of origin (φ). ε is an error term (see Table 2 for variable definition and descriptive statistics; the correlation matrix is shown in Table A.1 in the Appendix).

Insert Table 2 about here

To derive a per capita production function, we then divide both sides of the term by the number of employees (L) and get the following regression equation:

$$\ln\left(\frac{Value\_Added}{L}\right) = \alpha \ln\left(\frac{Energy\_Costs}{L}\right) + \beta \ln\left(\frac{Green\_Investments}{L}\right) + \gamma \ln\left(\frac{Non\_Green\_Investments}{L}\right) + \delta \ln\left(\frac{R\&D\_Expenditures}{L}\right) + \rho \ln(L) + \mu + \varphi + \varepsilon. \tag{2}$$

In order to test our predictions directly, the next step is to add the interaction term between a firm's energy costs and its investments in green energy technologies as an explanatory variable. Our baseline regression equation is thus defined as

$$\ln\left(\frac{Value\_Added}{L}\right) = \alpha \ln\left(\frac{Energy\_Costs}{L}\right) + \beta \ln\left(\frac{Green\_Investments}{L}\right) + \theta \ln\left(\frac{Energy\_Costs}{L}\right) * \ln\left(\frac{Green\_Investments}{L}\right) + \gamma \ln\left(\frac{Non\_Green\_Investments}{L}\right) + \delta \ln\left(\frac{R\&D\_Expenditures}{L}\right) + \rho \ln(L) + \mu + \varphi + \varepsilon. \tag{3}$$

Based on the coefficients β and θ, we can then identify the direction of the effect of increasing investment in green energy technologies by 1 euro per capita for different levels of the companies' energy costs. According to our first prediction (see Section 2.1), we expect that the interaction term shows a positive effect, that is, θ is positive. According to our second prediction (see Section 2.2), the total effect of investments in green energy technologies on productivity (i.e., the sum of β and θ) should only be positive for companies with high energy costs.

As mentioned in Section 3, the used data are based on a single survey conducted in 2015. This means that most of the model information referrers to 2014. An exception is the information on investments in green energy technologies. Because firms irregularly invest in such technologies, this information was asked for in the survey directly as an average for the years 2012 to 2014 (see Table 1). Moreover, information on energy costs, non-green investments, R&D expenditures and firm size was requested for 2014 as well as for 2012. As we discuss below, this makes it possible to account for certain dynamics in the model.

A general problem of empirical models is potential endogeneity, which can include both an omitted variable bias and reverse causality.[16] Using an instrumental variable (IV) is probably the first-best approach to tackle possible endogeneity. Unfortunately, finding instruments that are truly exogenous is difficult in practice. Specific policy shocks are often used in literature for this purpose. Policy shocks, however, are mostly country specific, which makes it difficult to find instruments that are valid for all three countries. Moreover, because our main focus is on the interaction term between a firm's energy costs and its investments in green energy technologies, we have to deal with possible endogeneity of more than one model variable. Using an IV approach would thus require at least three valid instruments. In practice, however, it is nearly impossible to find so many instruments (Angrist & Pischke 2008).

The inclusion of firm fixed effects, often seen as the second-best approach, does not make sense in our case either. By controlling for the firms' fixed characteristics, we would use the variation of a firm's energy costs over time to identify the energy cost effect. However, because green investments should directly affect a firm's energy costs, the variation in those costs over time is already an outcome of green investments. Instead, the focus of this paper is on how a firm's time-invariant energy costs act as a moderator of the effects of green investments on productivity. To identify this effect we therefore need variation in the energy costs across firms. This need for variation across firms also indicates that the absence of within-firm variation over time, one of the major disadvantages of the use of (quasi) cross-sectional data, is not so important for our study.

[16] The literature that investigates the effect of investments in tangible assets on productivity, for example, discusses the problem of confounding factors, such as expenses for repairing and maintenance, which typically leads to an underestimation of the "pure" investment effect (Grazzi et al. 2016; Nilsen et al. 2009; Power 1998). This problem is less important in our case, because our definition of green energy investments excludes such expenses (see Table 1). Moreover, the focus of this paper is on the direction of the investment effect (depending on the energy costs of the companies), and the exact size of the effect is less important. An underestimation of the investment effect would therefore hardly affect the interpretation of our results.

For this reason we use an ordinary least square model (OLS), but we significantly reduce the potential endogeneity problem in three ways. Firs, as an extension to the baseline regression (equation 3), we add the lagged dependent variable as an additional model variable to control for individual effects without using a fixed-effects setup (Angrist & Pischke 2008; Wooldridge 2002). The results of this extension are presented in column 3 of Table 3. Second, we reduce a potential omitted variable bias by controlling, next to energy input and investments in green energy technologies, for a broad set of observables affecting firm productivity. In addition to the model variables already included in our baseline regression (equation 3), an extension controls for additional company characteristics and the political environment (see columns 1 to 3 of Table A.5 in the Appendix). Third, as most variables were measured for 2012 and 2014, we deal with possible causality issues by lagging most of the explanatory variables such as the measures for energy costs, non-green investments, R&D expenditures and firm size (see column 4 of Table A.5). Hence, instead of using within-firm variation to identify the effect of green investments and energy costs, we use variation across firms with similar characteristics in terms of industry affiliation, firm size, lagged productivity, non-green investments, and so on.

5 Estimation results

5.1 Main results

Table 3 shows our main results, with our baseline regression equation (3) being shown in column 2. To obtain an idea of the magnitude of the direct effect of green investments, column 1 first presents our regression equation (2), which excludes the interaction term. In column 3, we then present a first extension to the baseline regression, which includes the firms' lagged productivity as an additional control to our model.

In column 1, we see that the direct effect of investments in green energy technologies on firm productivity is almost zero. The direct effect, however, turns negative when we add a control for the indirect effect via the firms' energy costs (column 2), and the negative effect becomes statistically significant at the 5% test level, when we add an additional control for the lagged dependent variable (column 3). The interaction effect between green energy adoption and energy costs shows the expected positive sign. In other words, the adoption of green energy technologies leads to larger productivity effects if a firm has high energy costs than if it has low energy costs.

Insert Table 3 about here

To illustrate this conditionality, Figure 2 shows the average marginal effects of green energy technologies, that is, the effect of increasing investments in green energy technologies by 1 euro per capita, on labor productivity (vertical axis) conditional on the level of energy costs (horizontal axis).[17] In line with our first prediction (see Section 2.1), the positive slope of this graph illustrates the moderating effect of energy costs on the effect of the adoption of green energy technologies on productivity. The confidence interval, which provides information on the area in which the marginal effect of investments in green energy technology is statistically significant, shows that the effect of green energy investments on productivity is significantly larger for firms with high energy costs than it is for firms with low energy costs.

Moreover, we see that the graph crosses the line where a marginal effect of zero is observed. Together with the confidence interval this allows us to distinguish three groups of firms. The first group consists of firms for which investments in green energy technologies has a significantly negative effect on firm productivity. These are all companies with yearly energy costs below 200 euros per capita, which in Figure 2 is exactly where the upper bound of the confidence interval crosses the line of a marginal effect of zero. For these companies, green investments thus seems to be mainly driven by intrinsic motivation, which is an important driver of green investments in general (see Arvanitis & Ley 2013). However, it is also possible that these negative short-term effects on production inputs can be offset in the longer run by positive image and prestige effects. Since this is the group of firms with the lowest energy costs, we refer to it in the following section as *low energy cost companies.*

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[17] As the inclusion of the lagged dependent variable significantly reduces a potential endogeneity problem (see Wooldridge 2002, p.174), this figure is based on the results presented in column 3 of Table 3.

Companies for which no statistically significant effect of investments in green energy technologies on firm productivity can be identified form a second group of companies. These are all companies with yearly energy costs between 200 and 5400 euros per capita, which in Figure 2 is exactly where the lower bound of the confidence interval crosses the line of a marginal effect of zero. In the following, we refer to these firms as *medium energy cost companies*.

Finally, a third group consists of companies for which statistically significant positive effects of investments in green energy technologies on firm productivity are observed, namely, those firms with yearly energy costs of more than 5400 euros per capita. Because this is the group with the highest energy costs, these companies are referred to as *high energy cost companies*.

Insert Figure 2 about here

In line with our second prediction (see Section 2.2), our results indicate that it is primarily high energy cost firms which can pick the low-hanging fruits. It is likely that the different effects on firm productivity also affect the firms' willingness to invest in green energy technologies. Although firms with negative productivity effects may not be willing to invest in green technologies without external interventions, firms with positive productivity effects are probably disposed to invest in such technologies by themselves. To understand the relative importance of the three groups of firms, we present descriptive information that is representative for the firm population of each of the three countries (see Table 4).[18] The low energy cost firms are relatively unimportant in terms of the number of firms (8.4% of the firms) and in terms of their energy consumption (0.1% of industry's total energy costs). Hence, the ecological consequences seem to be rather moderate if these firms are not willing to invest heavily in green energy technologies. The medium energy cost firms are much more important in the number of firms (72.6%), but less so with respect to their energy consumption (32.5%

[18] To obtain representative information, all these figures are based on data that were weighted according to the sampling schemes of the three countries.

of total energy costs). Fewer firms belong to the high energy cost firms (19.0%), but due to their high energy intensity, these firms are responsible for most of the total energy costs (68.4%).[19]

Insert Table 4 about here

To find out where the greatest potential for additional green investment might be, we consider the adoption rates and intensities of the three groups of firms observed in our data (see the bottom part of Table 4). As expected, the firms' adoption activity increases with increasing energy costs. However, there remains room for improvement regarding the adoption rate of the high energy cost firms (38.2%), which is slightly below the respective rate of the medium energy cost firms (38.5%). Moreover, both the medium (16.4%) and high (21.5%) energy cost firms have a rather low adoption intensity compared with the low energy cost firms (21.8%).

5.2 Robustness

These results withstand several robustness tests. First, we test the impact of adding several potential omitted variables to our main empirical model, such as the education level of the employees, the age of the firm, whether the firm was foreign owned or whether it was part of a group of companies (columns 1 and 2 of Table A.5 in the Appendix). For example, one may argue that whether a company has autonomy over their commercial space is an important driver of its adoption of green energy technologies and may thus also affect our main findings. By controlling for foreign ownership or the belonging to a group of companies in general, we try to prevent such a bias directly. Moreover, we also add controls for the firms' exposure to green politics[20] (column 3 of Table A.5), which may be particularly important, because it is possible that policy-induced adoption differently affects productivity than market-induced adoption does.

[19] Interestingly, similar figures are found in official statistics. According to EIA (2016), non-energy-intensive industrials make up approximately 30% and 36% of total OECD and non-OECD industrial sector energy consumption, respectively.
[20] This information comes from questions in the survey, where the firms were asked directly to assess the relevance of different green policy measures on a three-point Likert scale (see Table 2). Such measures are often used in literature to investigate the effect of different types of environmental policy at a company level (see, e.g., Horbach et al. 2012, Lanoie et al. 2011, Stucki and Woerter 2016).

Second, we deal with reverse causality concerns by lagging most explanatory variables by one time period (column 4 of Table A.5). Third, in order to test whether our findings are solely driven by a switch from a non-adopting to an adopting firm instead of an increase in the investments in green energy technologies, all firms with no green energy adoption activities are excluded in another regression (column 1 of Table A.6). Fourth, in order to deal with possible extreme values of the firms' energy costs, those firms with the 5% highest energy costs per capita are excluded (column 2 of Table A.6). Fifth, to test whether our findings differ by the firms' country of origin, we also regress our baseline model separately for Germany and Switzerland (columns 3 and 4 of Table A.6).[21]

Finally, investments such as changing light bulbs and rethinking the company's production process may not be equivalent and returns to productivity differ between different types of investments. In other words, returns to an investment of 1 euro in light bulbs are not the same as returns for 1 euro invested in a more efficient production process. Because the type of investments may vary with a firm's energy costs, it is not the amount of low hanging fruit, but the type and size of the fruit that can be picked by a firm, which may drive our results. Our data set allows us to distinguish the following fields of investments in green energy technologies: (a) production (e.g., electrical machines and drive systems), (b) information and communication technology (e.g., energy-saving servers), (c) transport (e.g., engines, electric cars), (d) building technology (e.g., temperature isolation, lighting, heating, air ventilation), and (e) green energy generation (e.g., solar systems, wind power plants, hydroelectric power plants). To test whether our results differ across the different fields of investments, we estimate our main model separately for the different fields of green technology adoption (see Table A.7).

All these tests indicate that our results are robust in the size and significance of the main effects which refer to the firms' investments in green energy technologies. Only in the models that are based on a much smaller sample size the effects turn out to be weakly significant at the 15% test level (models that are based on lagged explanatory variables, exclude firms without green adoption

[21] Due to the low number of observations, no separate regression is possible for Austria.

activities, or consider only Swiss firms), or even become insignificant (estimations for different fields of green technology adoption).

6 Conclusions

This paper analyzes the relationship between a firm's energy costs and the productivity effects of investments in green energy technologies based on representative firm-level data from Austria, Germany, and Switzerland. Different results are found for firms with low, medium and high energy costs. While the productivity effects of investment in green energy technologies turn out to be significantly positive for firms with high energy costs, no significant effects are found for firms with medium energy costs, and the effects are even significantly negative for firms with low energy costs.

So is it so that managers systematically overlook profit opportunities by not using green technologies more often, as is suggested by many scholars in this field of research (see, e.g., Majumdar & Marcus 2001; McWilliams & Siegel 2001; Porter & van der Linde 1995)? At least with respect to the use of green energy technologies, our results indicate that this is not the case with most Western companies. Due to the low energy costs, possible efficiency gains are marginal for most firms, which results in insignificant or even negative productivity effects of investments in green energy technologies. This is the case for 81% of the firms in our sample. So it is not surprising that most firms' investments in these technologies remain modest.

For companies with high energy costs, however, the answer is different. In our sample, the productivity effects of investment in green energy technologies is positive for the 19% of firms with the highest energy costs. Hence, these firms may actually increase their productivity by increasing their investment in green energy technologies. That adoption activities in these companies are nevertheless comparatively low indicates that the managers of these companies do effectively overlook profit opportunities.

Our findings also provide insights into a firm's incentives to invest in green energy technologies. Our results indicate that investments in green energy technologies may not pay off for companies with low and medium energy costs. This finding implies that firms with low and medium energy costs are unlikely to be willing to increase their investments in green energy technologies on their own initiative. However, a broader diffusion of green technologies is required to achieve climate goals (IPCC 2014). If society wants these companies to increase their use of green energy technologies, political intervention is required.

Political interventions may make little sense for companies with low energy costs because relatively few firms belong to this group and their energy consumption is low. Moreover, these firms already show substantial adoption activity. Excluding these firms from political interventions would not have severe ecological consequences. Instead, the main focus should be on firms with medium and high energy costs. Due to their large numbers, firms with medium energy costs are responsible for a considerable part of the energy consumption of companies. However, low economic returns keep their investments in green energy technologies at a modest level. Public subsidies could be used to make such investments more profitable for these companies (Jaffe et al. 2005; Peters et al. 2012; Veugelers 2012). Regulation could also force these companies to increase their investments in green energy technologies. However, because these investments do not have a positive impact on the productivity of these companies, there is a risk that pushing them into such investments without simultaneously increasing the economic returns of the investments could reduce the firms' competitiveness.

Political intervention is also required for firms with high energy costs. Although our results indicate that these companies would, on average, generate positive economic returns from green energy investments, we also note that their green energy investment behavior remains modest. Regulatory pressure can be used to signal these firms about likely resource inefficiencies and to make green innovation more attractive (Berrone et al. 2013; Costantini et al. 2015; Porter & van der Linde 1995).

These results have a number of policy implications. First, low economic returns indicate that policy intervention is needed to increase the attractiveness of investments in green energy technologies and boost the diffusion of these technologies. Second, the choice of the optimal policy instrument may depend on the energy costs of companies. While regulations may be optimal for firms with high energy costs to increase their investments in green energy technologies, subsidies may be more efficient for firms with medium energy costs. Third, if a group of companies is to be exempted from political intervention, then it should be the firms with the lowest energy costs. However, what typically occurs is that highly energy-intensive companies are exempted from everyday political debates because it is feared that their competitiveness will be disproportionately weakened by an intervention (see, e.g., CO_2 tax in Switzerland).

The focus of this paper has been on green energy technologies. Yet it is likely that many of its findings also apply to green investments in general, because most energy consumption as well as most environmental pollution is caused by relatively few firms in Western countries. Some evidence for this wider applicability can be seen in Hart and Ahuja (1996) and in Ruggiero and Lehkonen (2016), who found larger effects for emission reduction and renewable energy production, respectively, on the operating and financial performance of firms with higher emissions levels than on those of firms with lower emissions levels. Further theoretical and empirical investigations are required to test whether our findings apply to the adoption of other types of green technologies as well.

Moreover, it would be interesting to determine if our findings could be extended to other countries. Because the results are robust for Austria, Germany and Switzerland, it indicates that the findings may be transferable to other Western countries. Future studies could examine if this is indeed the case. In addition, because the energy costs of companies in developing countries typically have a greater variance, it could be tested how our results apply to developing countries.

Another potential issue would be to test the robustness of our results for different industries. Given the large number of control variables in our model, the number of observations at this level of aggregation is too low to identify significant effects for most industries. Industry-specific studies will be required to test the robustness of our findings for different industries.

By including the main variables in an extensive model that controls for the most common drivers of firm productivity, we significantly reduced a potential endogeneity problem. Yet as already mentioned, it was difficult to deal with the endogeneity issue directly in our model. Future studies could test the robustness of our findings using natural experiments or specific case studies. Finally, our results suggest that the choice of the optimal policy instrument may depend on the energy costs of companies. Future studies should investigate if this is indeed the case.

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Figure 1: Testing the moderating effect of the firms' energy costs

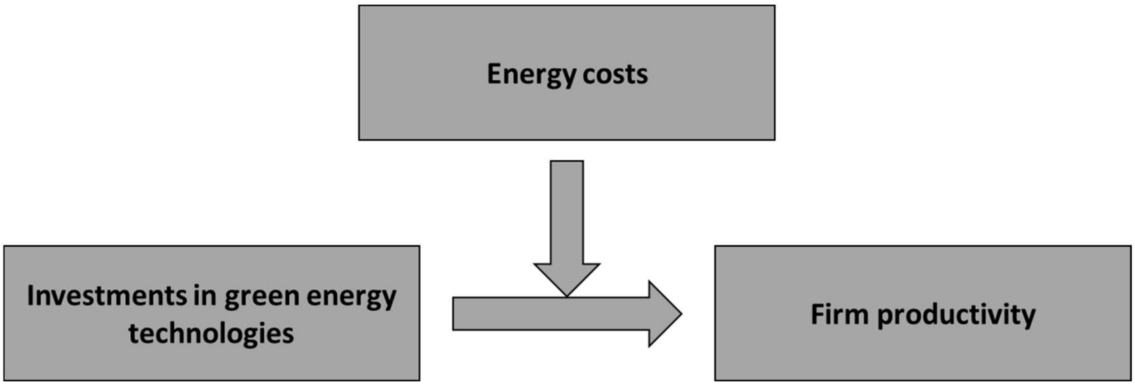


Table 1: Relevant questions in the survey

Q1.9. Share of energy costs in sales in 2012 and 2014.
Q4.1. Has your company introduced at least one of the following energy technologies for use in your own company in the period 2012 – 2014 (yes/no):

a) Energy-saving technologies in the field:
   - Production (e.g., electrical machines and drive systems),
   - Information and communication technology (ICT, e.g., energy-saving servers)
   - Transport (e.g., engines of motor vehicles, electric cars)
   - Building technology (e.g., temperature isolation, lighting, heating, air ventilation)
   - Other energy-saving technologies/procedures (e.g., more efficient gas turbines, cogeneration of heat and power), which are …
b) Technologies for the use of energy from renewable sources (e.g., solar systems, wind power plants, hydroelectric power plants).

Q 4.2. Proportion of investments for the introduction of these technologies in your company's total investments on average for the years 2012 to 2014.

Table 2: Variable definition and descriptive statistics

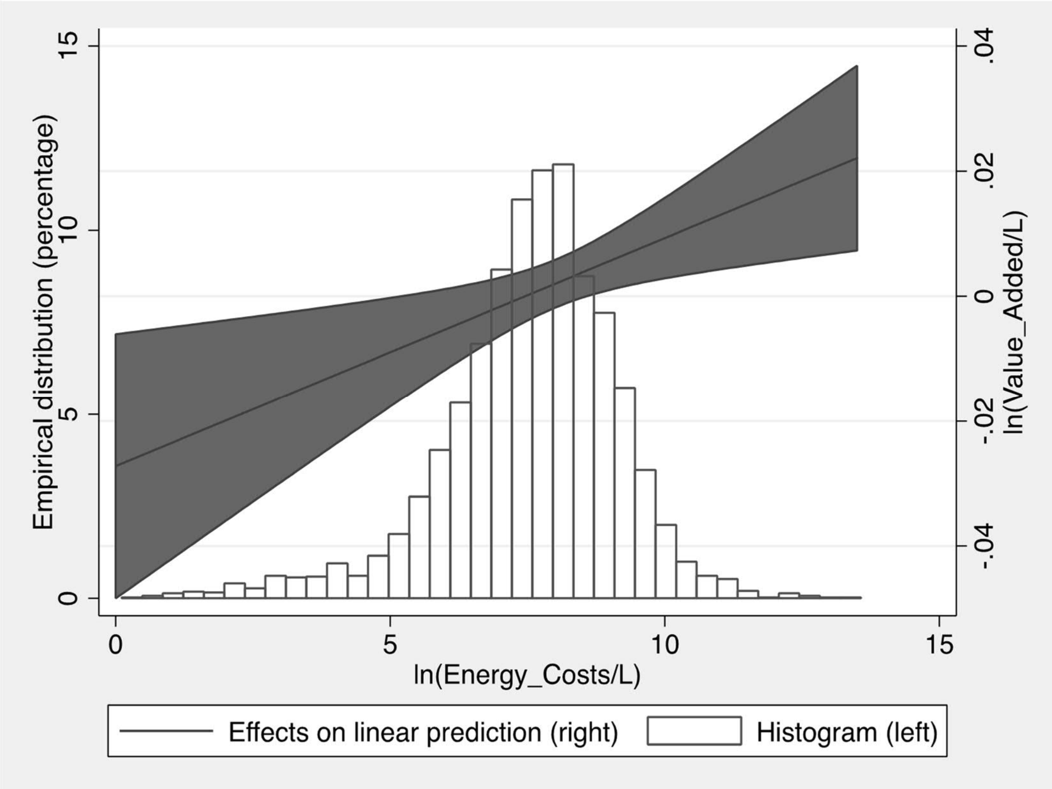
Variable	Definition/measurement	Mean	Std. Dev.	Min	Max
Value_Added/L	Value added per capita (in Euro), whereby value added is defined as sales minus purchasing costs	140482.00	351510.30	17.02	1.28E+07
Green_Investment/L	Gross investment expenditures for green energy technologies per capita (in Euro); as firms often invest irregularly in green energy technologies, these investments are measured as an average over the period 2012-2014	736.75	4949.07	0	273172
Energy_costs/L	Yearly energy costs per capita (in Euro)	5603.29	19714.52	0.11	783500
Non_Green_Investment/L	Gross investment expenditures per capita excluding expenditures for green energy technologies (in Euro)	11255.77	43103.63	0	1659459
R&D_Expenditures/L	Total R&D expenditures per capita (in Euro)	6588.38	161880.10	0	9891197
L	Number of employees measured in full-time equivalents	281.21	2418.89	1	112305
Share_of_High_Qualified_Employees	Share of employees with a tertiary-level degree	18.35	24.11	0	150
Foreign_Owned	Firm is foreign owned yes (value 1)/no (value 0)	0.11	0.31	0	1
Firm_Age	Age of the firm	47.94	42.62	1	515
Group of companies	Firm is part of a group of companies yes (value 1)/no (value 0)	0.32	0.47	0	1
Taxes	Firm-specific relevance of energy related taxes (three-level ordinary variable; level 1: 'not relevant'; level 3: 'high relevance')	1.69	0.74	1	3
Regulations	Firm-specific relevance of energy related regulations (three-level ordinary variable; level 1: 'not relevant'; level 3: 'high relevance')	1.47	0.68	1	3
Voluntary_Agreements	Firm-specific relevance of energy related voluntary agreements (three-level ordinary variable; level 1: 'not relevant'; level 3: 'high relevance')	1.38	0.62	1	3
Public_Subsidies	Firm-specific relevance of energy related public subsidies (three-level ordinary variable; level 1: 'not relevant'; level 3: 'high relevance')	1.43	0.67	1	3
Swiss_Firm	Switzerland is the firm's country of origin yes (value 1)/no (value 0)	0.40	0.49	0	1
German_Firm	Germany is the firm's country of origin yes (value 1)/no (value 0)	0.49	0.50	0	1

Table 3: Main results (based on OLS regressions)

	(1)	(2)	(3)
	ln(Value_Added/L)$_{2014}$		
ln(Green_Investment/L) $_{ø2012\text{-}2014}$	0.004	-0.038	-0.027**
	(0.003)	(0.024)	(0.013)
ln(Energy_Costs/L)$_{2014}$	0.079***	0.068***	0.030***
	(0.009)	(0.010)	(0.007)
ln(Energy_Costs/L)$_{2014}$*ln(Green_Investment/L) $_{ø2012\text{-}2014}$		0.005*	0.004**
		(0.003)	(0.002)
ln(Non_Green_Investment/L)$_{2014}$	0.025***	0.026***	0.012***
	(0.005)	(0.005)	(0.003)
ln(R&D_Expenditures/L)$_{2014}$	0.010***	0.010***	0.002
	(0.003)	(0.003)	(0.002)
ln(L)$_{2014}$	0.027***	0.027***	0.012**
	(0.007)	(0.007)	(0.005)
ln(Value_Added/L)$_{2012}$			0.668***
			(0.025)
Swiss_Firm	0.472***	0.471***	0.122***
	(0.029)	(0.029)	(0.021)
German_Firm	-0.001	0.001	0.028
	(0.031)	(0.031)	(0.021)
Constant	10.793***	10.171***	3.207***
	(0.803)	(0.225)	(0.289)
Industry controls	yes	yes	yes
N	4420	4420	4420
R^2	0.28	0.28	0.62
adj R^2	0.27	0.27	0.61
Log Likelihood	-4129.17	-4125.62	-2727.54

Notes: see Table 2 for the variable definitions; robust standard errors are in brackets under the coefficients; ***, **, * denote statistical significance at the 1%, 5% and 10% test level, respectively.

Figure 2: Marginal effect of green energy investments on labor productivity conditional on the level of energy costs (based on baseline results presented in Column 3 of Table 2)



Note: 90% confidence interval is plotted in grey.

Table 4: Characteristics of the three groups of firms

	Energy costs		
	Low	Medium	High
Relevance			
Relative share in the industrial sectors' total number of firms	8.4%	72.6%	19.0%
Relative share in the industrial sectors' total energy costs	0.1%	31.5%	68.4%
Adoption behavior			
Ratio of firms with green energy adoption activities	19.6%	38.5%	38.2%
Average share of green energy investments in total investments (adopting firms)	21.8%	16.4%	21.5%
Average share of green energy investments in total investments (all firms)	4.1%	5.5%	6.8%

Note: In order to obtain representative information, all these figures are based on data that are weighted according to the sampling schemes of the three countries.

APPENDIX

Table A.1: Correlation matrix

	ln(Value_Added/L)$_{2014}$	ln(Green_Investment/L) $_{ø2012\text{-}2014}$	ln(Energy_Costs/L)$_{2014}$	ln(Non_Green_Investment/L)$_{2014}$	ln(R&D_Expenditures/L)$_{2014}$	ln(L)$_{2014}$	ln(Value_Added/L)$_{2012}$	Swiss_Firm
ln(Green_Investment/L) $_{ø2012\text{-}2014}$	0.09							
ln(Energy_Costs/L)$_{2014}$	0.25	0.22						
ln(Non_Green_Investment/L)$_{2014}$	0.24	0.31	0.27					
ln(R&D_Expenditures/L)$_{2014}$	0.06	0.16	0.05	0.13				
ln(L)$_{2014}$	0.17	0.30	0.13	0.28	0.23			
ln(Value_Added/L)$_{2012}$	0.77	0.07	0.22	0.22	0.06	0.16		
Swiss_Firm	0.35	-0.06	0.18	0.20	-0.04	0.12	0.39	
German_Firm	-0.31	-0.01	-0.22	-0.24	-0.01	-0.19	-0.34	-0.80

Notes: N= 4,420; based on same sample as main model presented in Table 3.

Table A.2: Proportion of companies investing in green energy technologies by field and industry (basis: companies investing in green energy technologies)

	Production	ICT	Transport	Building technology	Green energy generation
Food/Beverages/Tobacco	49.2%	19.2%	12.2%	55.8%	28.7%
Textiles/Clothing	50.6%	26.9%	11.8%	86.8%	24.2%
Wood	70.3%	18.2%	27.4%	59.9%	48.9%
Paper	66.9%	43.3%	29.8%	83.3%	0.0%
Printing	86.5%	44.8%	21.0%	62.7%	23.4%
Chemicals	70.8%	55.5%	22.4%	55.8%	5.6%
Pharmaceuticals	14.1%	19.4%	2.2%	95.0%	66.0%
Rubber/Plastics	86.5%	27.3%	12.3%	76.0%	18.4%
Non-metallic Minerals	52.3%	35.9%	21.2%	70.5%	22.6%
Basic Metals	90.0%	42.0%	5.5%	80.7%	20.0%
Fabricated Metals	52.8%	31.4%	15.2%	60.5%	31.4%
Machinery & Equipment	41.7%	45.3%	30.8%	74.6%	18.7%
Electrical Equipment	27.7%	49.7%	14.9%	74.1%	17.2%
Electronic and Optical Products	34.7%	59.9%	9.9%	74.0%	19.9%
Repair/Installation	45.4%	52.3%	23.5%	73.8%	20.3%
Medical Instruments	23.5%	56.0%	28.9%	77.2%	7.1%
Vehicles	22.9%	59.3%	4.4%	85.8%	2.7%
Other Manufacturing	58.8%	56.2%	43.3%	76.0%	12.6%
Water/Environment	53.1%	32.1%	50.3%	60.2%	26.4%
Construction	9.2%	40.3%	16.4%	67.5%	26.4%
Wholesale Trade	19.4%	45.9%	53.8%	62.1%	32.4%
Retail Trade	16.4%	34.7%	34.3%	61.1%	23.7%
Accommodation/Restaurants	71.0%	31.6%	15.9%	85.8%	15.1%
Transportation	8.4%	33.4%	85.7%	47.9%	16.6%
Telecommunications	31.7%	5.3%	94.3%	34.0%	32.5%
Publishing/Media	1.9%	31.2%	69.8%	22.1%	6.0%
Information Technology/Services	4.6%	91.4%	7.7%	40.0%	16.6%
Banks/Insurances	3.9%	84.7%	10.6%	63.3%	13.3%
Real Estate/Rental & Leasing	18.1%	48.0%	31.5%	66.3%	16.6%
Technical Commercial Services	9.5%	70.1%	9.8%	61.7%	27.1%
Other Commercial Services	19.7%	47.8%	25.8%	67.3%	13.8%
Personal Services	94.3%	13.5%	11.9%	20.2%	1.4%
Total	27.5%	43.9%	30.5%	63.0%	22.4%

Table A.3: Variance in the firms' investments in green energy technologies within industry

	Green_Investment/L			
	p25	p50	p75	p90
Food/Beverages/Tobacco	0.0	86.1	601.0	3030.3
Textiles/Clothing	0.0	0.0	483.3	1600.0
Wood	0.0	0.0	811.5	1833.3
Paper	0.0	227.0	762.0	1997.9
Printing	0.0	0.0	450.5	1715.7
Chemicals	0.0	0.0	737.5	3009.7
Pharmaceuticals	0.0	0.0	1149.6	1923.1
Rubber/Plastics	0.0	114.6	907.9	2897.5
Non-metallic Minerals	0.0	0.0	972.2	3376.5
Basic Metals	0.0	334.1	1439.1	3200.0
Fabricated Metals	0.0	0.0	400.0	1666.7
Machinery & Equipment	0.0	0.0	456.7	1862.8
Electrical Equipment	0.0	0.0	400.0	1106.2
Electronic and Optical Products	0.0	0.0	129.4	800.0
Repair/Installation	0.0	0.0	200.0	365.0
Medical Instruments	0.0	0.0	338.5	1800.0
Vehicles	0.0	0.0	251.7	1356.3
Other Manufacturing	0.0	130.5	553.9	1346.2
Water/Environment	0.0	179.3	1547.1	4678.3
Construction	0.0	0.0	138.5	675.5
Wholesale Trade	0.0	0.0	444.4	1820.9
Retail Trade	0.0	0.0	194.1	1075.9
Accommodation/Restaurants	0.0	0.0	484.5	1218.8
Transportation	0.0	0.0	868.1	2441.7
Telecommunications	0.0	0.0	452.1	2441.7
Publishing/Media	0.0	0.0	115.4	571.4
Information Technology/Services	0.0	0.0	48.4	903.4
Banks/Insurances	0.0	0.0	358.0	1125.0
Real Estate/Rental & Leasing	0.0	0.0	106.2	1742.8
Technical Commercial Services	0.0	0.0	20.0	521.0
Other Commercial Services	0.0	0.0	0.0	340.9
Personal Services	0.0	31.1	441.2	1666.7
Total	0.0	0.0	359.3	1500.0

Table A.4: Variance in the firms' energy costs across and within industry

	Energy_Costs/L	Share of companies by level of energy costs Low	Medium	High
Food/Beverages/Tobacco	4,822.3	0.0%	74.1%	25.9%
Textiles/Clothing	5,450.0	0.5%	71.2%	28.3%
Wood	5,066.3	0.3%	59.2%	40.5%
Paper	7,482.9	7.1%	59.3%	33.6%
Printing	5,349.0	0.0%	80.4%	19.6%
Chemicals	9,879.1	1.0%	74.5%	24.5%
Pharmaceuticals	5,864.5	0.0%	55.5%	44.5%
Rubber/Plastics	4,460.7	0.0%	72.9%	27.1%
Non-metallic Minerals	5,643.0	6.7%	65.9%	27.4%
Basic Metals	6,942.1	1.8%	57.3%	40.9%
Fabricated Metals	4,155.1	2.7%	79.2%	18.1%
Machinery & Equipment	5,559.1	11.9%	78.2%	9.9%
Electrical Equipment	1,950.1	1.3%	93.8%	5.0%
Electronic and Optical Products	1,535.1	6.2%	91.2%	2.6%
Repair/Installation	1,705.2	2.0%	95.9%	2.1%
Medical Instruments	3,062.5	0.0%	85.0%	15.0%
Vehicles	2,444.5	2.3%	87.6%	10.1%
Other Manufacturing	10,670.3	5.6%	66.9%	27.5%
Water/Environment	11,047.1	4.1%	23.4%	72.6%
Construction	2,486.7	11.7%	72.6%	15.8%
Wholesale Trade	2,864.4	1.4%	91.1%	7.5%
Retail Trade	4,979.4	1.9%	63.3%	34.8%
Accommodation/Restaurants	11,802.9	0.1%	49.4%	50.5%
Transportation	10,160.1	15.0%	34.7%	50.3%
Telecommunications	13,585.6	6.5%	53.0%	40.6%
Publishing/Media	2,508.2	22.5%	63.1%	14.4%
Information Technology/Services	1,617.6	10.9%	82.7%	6.4%
Banks/Insurances	2,920.0	3.6%	71.6%	24.8%
Real Estate/Rental & Leasing	2,564.1	14.6%	76.2%	9.2%
Technical Commercial Services	2,463.9	2.7%	86.3%	11.0%
Other Commercial Services	1,823.9	16.5%	77.3%	6.1%
Personal Services	31,096.5	0.0%	55.5%	44.5%
Total	4,138.5	8.3%	72.5%	19.0%

Notes: To group the firms into the three levels of energy costs, we used the thresholds from our economic regressions (see Section 5).

Table A.5: Respecifications of the main model

	(1)	(2)	(3)	(4)
	ln(Value_Added/L)$_{2014}$			
ln(Green_Investment/L)$_{ø2012\text{-}2014}$	-0.027**	-0.023*	-0.027**	-0.025
	(0.013)	(0.013)	(0.013)	(0.016)
ln(Energy_Costs/L)$_{2014}$	0.033***	0.032***	0.030***	
	(0.007)	(0.007)	(0.007)	
ln(Energy_Costs/L)$_{2014}$*ln(Green_Investment/L)$_{ø2012\text{-}2014}$	0.004**	0.003*	0.004**	
	(0.002)	(0.002)	(0.002)	
ln(Non_Green_Investment/L)$_{2014}$	0.013***	0.014***	0.012***	
	(0.003)	(0.004)	(0.003)	
ln(R&D_Expenditures/L)$_{2014}$	0.001	0.001	0.002	
	(0.002)	(0.002)	(0.002)	
ln(L)$_{2014}$	0.009*	0.003	0.012**	
	(0.006)	(0.006)	(0.005)	
ln(Value_Added/L)$_{2012}$	0.658***	0.663***	0.667***	0.721***
	(0.027)	(0.027)	(0.025)	(0.026)
ln(Energy_Costs/L)$_{2012}$				0.000
				(0.007)
ln(Energy_Costs/L)$_{2012}$*ln(Green_Investment/L)$_{ø2012\text{-}2014}$				0.004*
				(0.002)
ln(Non_Green_Investment/L)$_{2012}$				0.007*
				(0.004)
ln(R&D_Expenditures/L)$_{2012}$				-0.000
				(0.002)
ln(L)$_{2012}$				0.015**
				(0.006)
ln(Share_of_High_Qualified_Employees)$_{2014}$	0.020***			
	(0.008)			
Foreign_Owned$_{2014}$	0.094***			
	(0.023)			
ln(Firm_Age)$_{2014}$	-0.004			
	(0.010)			
Group of companies		0.078***		
		(0.017)		
Taxes$_{ø2012\text{-}2014}$			-0.013	
			(0.012)	
Regulations$_{ø2012\text{-}2014}$			0.010	
			(0.013)	
Voluntary_Agreements$_{ø2012\text{-}2014}$			0.002	
			(0.013)	
Public_Subsidies$_{ø2012\text{-}2014}$			-0.008	
			(0.011)	
Swiss_Firm	0.125***	0.121***	0.120***	0.088***
	(0.022)	(0.022)	(0.021)	(0.023)
German_Firm	0.026	0.036*	0.030	0.015
	(0.022)	(0.021)	(0.021)	(0.027)
Constant	3.269***	3.206***	3.231***	2.792***
	(0.299)	(0.316)	(0.291)	(0.323)
Industry controls	yes	yes	yes	yes
N	4219	4012	4420	2842
R^2	0.63	0.61	0.62	0.71
adj R^2	0.62	0.60	0.61	0.70
Log Likelihood	-2551.62	-2450.58	-2726.62	-1407.76

Notes: see Table 2 for the variable definitions; robust standard errors are in brackets under the coefficients; ***, **, * denote statistical significance at the 1%, 5% and 10% test level, respectively.

Table A.6: Subsample analysis

	(1)	(2)	(3)	(4)
Sample:	Drop firms without adoption activities	Drop top 5% energy cost firms	Swiss firms only	German firms only
		ln(Value_Added/L)$_{2014}$		
ln(Green_Investment/L)$_{ø2012\text{-}2014}$	-0.038	-0.028**	-0.032	-0.033*
	(0.023)	(0.014)	(0.022)	(0.020)
ln(Energy_Costs/L)$_{2014}$	0.016	0.024***	0.019**	0.036***
	(0.019)	(0.007)	(0.009)	(0.012)
ln(Energy_Costs/L)$_{2014}$*ln(Green_Investment/L)$_{ø2012\text{-}2014}$	0.005	0.004**	0.004	0.004*
	(0.003)	(0.002)	(0.003)	(0.003)
ln(Non_Green_Investment/L)$_{2014}$	0.021***	0.010***	0.010	0.014***
	(0.005)	(0.004)	(0.006)	(0.004)
ln(R&D_Expenditures/L)$_{2014}$	0.002	0.002	0.005*	0.002
	(0.003)	(0.002)	(0.003)	(0.003)
ln(L)$_{2014}$	0.011	0.016***	-0.002	0.012
	(0.007)	(0.006)	(0.008)	(0.008)
ln(Value_Added/L)$_{2012}$	0.683***	0.651***	0.595***	0.694***
	(0.033)	(0.027)	(0.042)	(0.032)
Swiss_Firm	0.107***	0.130***		
	(0.026)	(0.022)		
German_Firm	0.042	0.017		
	(0.030)	(0.021)		
Constant	3.206***	3.375***	4.096***	3.195***
	(0.335)	(0.308)	(0.498)	(0.361)
Industry controls	yes	yes	yes	yes
N	2017	4198	1758	2169
R^2	0.67	0.60	0.52	0.59
adj R^2	0.66	0.59	0.50	0.58
Log Likelihood	-991.00	-2580.64	-902.42	-1521.55

Notes: see Table 2 for the variable definitions; robust standard errors are in brackets under the coefficients; ***, **, * denote statistical significance at the 1%, 5% and 10% test level, respectively.

Table A.7: Results by field of green technology adoption

	(1)	(2)	(3)	(4)	(5)
Field of adoption:	Production	ICT	Transport	Building technology	Green energy generation
			$\ln(Value\_Added/L)_{2014}$		
$\ln(Green\_Investment/L)_{ø2012\text{-}2014}$	-0.053	-0.024	-0.022	-0.037	-0.068
	(0.047)	(0.031)	(0.038)	(0.035)	(0.047)
$\ln(Energy\_Costs/L)_{2014}$	-0.010	0.060**	0.022	0.003	-0.026
	(0.039)	(0.024)	(0.035)	(0.026)	(0.040)
$\ln(Energy\_Costs/L)_{2014}*\ln(Green\_Investment/L)_{ø2012\text{-}2014}$	0.006	0.001	0.002	0.005	0.008
	(0.006)	(0.004)	(0.005)	(0.004)	(0.006)
$\ln(Non\_Green\_Investment/L)_{2014}$	0.025***	0.025***	0.014	0.026***	0.017
	(0.009)	(0.009)	(0.012)	(0.007)	(0.015)
$\ln(R\&D\_Expenditures/L)_{2014}$	0.005	-0.000	0.001	0.005*	-0.010
	(0.004)	(0.004)	(0.006)	(0.003)	(0.007)
$\ln(L)_{2014}$	0.011	0.031***	0.007	0.009	0.031**
	(0.010)	(0.009)	(0.012)	(0.009)	(0.014)
$\ln(Value\_Added/L)_{2012}$	0.711***	0.659***	0.677***	0.710***	0.639***
	(0.047)	(0.041)	(0.076)	(0.030)	(0.097)
Swiss_Firm	0.128***	0.105***	0.069	0.106***	0.154***
	(0.036)	(0.037)	(0.049)	(0.029)	(0.050)
German_Firm	0.081**	0.003	-0.042	0.072**	0.002
	(0.034)	(0.040)	(0.063)	(0.029)	(0.073)
Constant	3.032***	3.107***	3.411***	2.952***	4.005***
	(0.466)	(0.422)	(0.744)	(0.343)	(1.048)
Industry controls	yes	yes	yes	yes	yes
N	902	949	624	1426	449
R^2	0.71	0.71	0.66	0.70	0.67
adj R^2	0.69	0.68	0.62	0.68	0.61
Log Likelihood	-326.47	-426.76	-340.62	-649.07	-210.95

Notes: see Table 2 for the variable definitions; robust standard errors are in brackets under the coefficients; ***, **, * denote statistical significance at the 1%, 5% and 10% test level, respectively.