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# The adoption of green energy technologies: the role of policies in an international comparison\*

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**Abstract:** We contribute to the existing research about policy-induced technology adoption in several ways. First, we suggest a new survey design to measure the energy-related policy environment. Second, we simultaneously estimate the policy effects for the adoption propensity and the adoption intensity simultaneously and, third, we conduct an international comparison of the policy effects. Based on a representative sample of firms for Austria, Germany, and Switzerland we find that policies in all three countries essentially promote the adoption of technologies and they are practically ineffective for the intensity, which poses a great challenge to future policy designs. Voluntary agreements or demand related factors are among the most important drivers for the adoption propensity of green energy technologies. Given the current institutional framework in the surveyed countries, subsidies are more effective in Austria, taxes are more effective in Germany, and demand related factors are relatively more effective in Switzerland.

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## 1. Introduction

Despite the growing literature on the adoption of energy-efficient technologies and the well elaborated theoretical background on technology diffusion (Karshenas and Stoneman 1995, Battisti and Stoneman 2003, 2005), gaps remain in the empirical literature limiting our understanding of the effects of policies on the adoption of energy-related technologies.

First, current literature either focuses on the propensity of adoption (Veugelers 2012, Arvanitis and Ley 2013) or intensity of adoption (Stucki and Woerter 2016) rather than recognizing that the two activities have different features. Secondly, data availability seriously limits cross country comparisons depriving the possibility to identify policy effects based on identical definitions, an identical theoretical background, an identical model specification, considering country specific factors. With the paper at hand we address both issues. We simultaneously estimate the relationship between energy-related policies including voluntary measures and the propensity to adopt environmentally friendly energy technologies<sup>1</sup> (inter-firm) and the effect of policies on the intensity of investments in such technologies (intra-firm). Based on a representative panel of firms for Switzerland, Germany, and Austria, respectively, we collected data for all three countries using a commonly designed questionnaire. The surveys have been conducted by KOF (Swiss Economics Institute; Switzerland), ZEW (The Centre for European Economic Research, Germany), and WIFO (Austrian Institute of Economic Research, Austria). These are institutions with many years of experience in collecting survey data and the applied survey design has been frequently used to provide survey based information for official statistics in the respective countries.

An important contribution to the existing literature also refers to the measurement of the energy-related policy environment. Ghisetti and Pontoni (2015) conducted a meta-analysis of policy effects on environmental innovation and found that the operationalization of the policy information is crucial for the result. Hence, we made a great effort to measure policies as exactly and unbiased as possible using surveys as a tool for collecting this information. We wanted to avoid the frequently observed issue that policy information is only available for firms that adopted green energy technologies and we also wanted to avoid a potentially “common method bias” by posing a question that contains the type of policy and its effect in one sentence.<sup>2</sup> This led to a new design of the questionnaire where we excluded a direct link between the policy exposure and the adoption behavior of the firm. We asked firms to rate the importance of a series of energy-related factors, including government policies (taxes and levies, regulations, subsidies), voluntary agreements, demand related factors, and factors related to the energy environment (fluctuation of energy prices, (feared) bottlenecks in energy supply). Clearly, this question asks for a “subjective” response. The usual critic for this type of question (see Bertrand and Mullainathan 2001) does not necessarily apply, however. First, the respondents usually think of an “objective” event in the firm or in its environment, or an important discussion that helps him/her to decide if a policy-related factor is important or not. Second, the list of policy-related factors helps the respondents to

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<sup>1</sup> Energy technologies that increase the energy efficiency or that use renewable energy sources. Such Technologies may include tangible equipment as well as information and management systems, In the remainder of the paper, we use the term ‚green energy technology’ to denote these technologies.

<sup>2</sup> For instance: „Did the firm introduce and environmentally friendly technology in response to regulation x?”

assess the relative importance among the factors asked; which is important for the applied econometric analysis.

Based on a comprehensive data set—which allows for a rich control vector—covering the countries Austria, Germany, and Switzerland, we apply standard econometric procedures to identify the relationship between different policies and the propensity to install green energy technologies. Moreover, we identify their meaning for the investment intensity in such technologies. We can identify country differences for both aspects of adoption (propensity/intensity) and we can compare the results across different countries. We also investigate if firm characteristics—like “energy intensity”—drives the adoption. In a more explorative investigation we analyze if policy effects differ across technologies and if their effect differs between technology adoption and the adoption of environmental management systems (non-technology measures).

The direct comparisons of policy effectiveness for the propensity of adoption and the intensity of adoption, respectively, reveals some interesting insights. Policies in all three countries essentially promote the adoption of technologies and they are practically ineffective for the intensity, which poses a great challenge to future policy designs; the intensity of adoption is mainly driven by firm specific characteristics, like the energy costs of the focal firm and firm size. Only public subsidies show a significant and positive relationship with the investment intensity in green energy technologies. Voluntary agreements or demand related factors are among the most important drivers for the adoption of such technologies.

Exploratory estimations on technology specific effects of the investigated factors reveal that demand related factors and public subsidies are important for the adoption of all identified technologies (excluding transport), whereas the adoption of green energy technologies in the field of production is significantly driven by taxes and in the field of buildings voluntary agreements are very important. The adoption of energy management systems is driven by taxes, voluntary agreements and public subsidies.

In general, national promotion plans relying on subsidies and demand related factors appear to be effective for the adoption of a broad spectrum of technologies and green management systems. Taxes and voluntary agreements are also overall effective but they show some technology specific patterns, which can be due to the lack of initiatives related to such instruments. Given the current institutional framework in the respective countries, subsidies are more effective in Austria, taxes are more effective in Germany, and demand related factors are relatively more effective in Switzerland.

The paper is structured like follows. Section 2 briefly introduces the policy environment in the investigated countries. Section 3 provides a review of the literature and identifies relevant hypotheses to be tested in the empirical part of the paper. Section 4 presents some important details about the survey design and the data description. Section 5 deals with the econometric framework applied to test the hypotheses. Section 6 presents the results and in section 7 we conclude and point at important policy implications.

## 2. The policy environment in the specific countries

### *Switzerland*

Stucki and Woerter (2016) and Pellegrin and Woerter (2016) provide a brief description of the Swiss energy-related policy framework. Switzerland has rather few policy measures to promote the adoption and generation of energy-related technologies compared to, e.g., Germany. The Swiss framework is characterized by market incentives and voluntary agreements and there are also some important targeted policies. As of today (2016) there is a CO<sub>2</sub>-tax (levy; since 2008) that was part of the first commitment period of the Kyoto protocol and a Swiss emission trading system (for heavy polluters)—which is still very narrow—started in 2013. The tax for CO<sub>2</sub> has increased over time and amounts to 85 CHF per CO<sub>2</sub> ton in 2016. There is also an emission regulation for passenger cars—similar to the EU-regulations—which has been effective since 2012. A feed-in-tariff system has been already introduced in 1998 and a (subsidy) program for adoption of green technologies in the building sector, started in 2010. There are also regulations concerning labeling, promotion and installation of renewable energy plants. Public subsidies are available in form of a technology fund to promote innovative technologies that reduce greenhouse gas emissions and the consumption of resources. It also supports the use of renewable energy and an increase in energy efficiency. There are also subsidies for basic research and applied R&D in form of pilot plants for economical and efficient use of energy and use of renewable energies. Hence, all types of policy measures are used to promote the adoption/generation of environmentally friendly technologies in Switzerland (regulations, taxes, subsidies), however, 41% of Swiss firms bring some importance to the tax regime (11% high importance), 33% to regulation (9% high importance) and 27% to subsidies (7% high importance). Like assumed above, voluntary agreements and demand related factors are perceived as relatively more or of equal importance compared to the comparison countries Austria and Germany, respectively (see Arvanitis et al. 2016).

### *Germany*

Energy policy in Germany has been characterized in the past 25 years by a strong focus on renewable energies (Lehr and Lutz 2016). Renewable energy sources, particularly biomass, solar and wind energy, are expected to substitute electric energy production from nuclear power which is to fade out by 2022 (. At the same time, a growing share of renewable energy sources should help reaching the ambitious low-carbon targets of the German government (-40% by 2020 as compared to the 1990 level, -80% by 2050; see BMWi 2012) (Lutz et al. 2014, Pregger et al. 2013). The Federal Government has introduced a series of laws and regulations to stimulate the shift in energy sources towards renewable energy. In 1991, the Electricity Feed-in Act obliged electric utility companies to take electric energy from renewable sources at a guaranteed feed-in tariff from local and regional renewable energy producers. In 2000, the Act was succeeded by the Renewable Energy Act. The fixed feed-in tariff was set at a level that guaranteed profitable production and was reduced in regular intervals in order to stimulate efficiency improvements (Büsgen and Dürrschmidt 200). The additional costs for utility companies are passed on to consumers (both households and enterprises) through a special item (renewable energy surcharge) in the electricity bill (Nolden 2013). Energy-intensive industries as well as firms with substantial own electricity production are partly exempted from the surcharge. For producers of renewable energy technologies, the legislation provided them with a home market advantage and led to the emergence of an innovative industry (Cantner et al. 2016, Lauber and Jacobsson 2016, Yu et al. 2016, Welfens and Lutz, 2012). For electricity consuming firms, the renewable energy policy in Germany resulted in a constant

increase in electricity prices and provided an incentive to invest into own electricity producing facilities based on renewable energy (particularly photovoltaic energy and biomass) (Lehr et al. 2009, 2012, Lipp 2007, Frondel et al. 2010). The trend to increasing electricity prices has been reinforced by an ecological tax reform in 1999, including the introduction of a new electricity tax. In addition, the petroleum tax has been redesigned to provide more incentives for investment in energy-saving vehicles.

Further energy-related policy measures include the CO2 Building Rehabilitation Programme which provided incentives for energy-efficient building refurbishment (Rosenow 2013). The program is regarded as highly effective, having incentivized innovation both for building technology producers and house owners, including firms (Schroeder et al. 2011, Kuckshinrichs et al. 2010, Kronenberg et al. 2012, Galvin 2012). The German Federal Government is also running several R&D programs that foster the development of energy-saving technologies, The Federal Government's 6th Energy Research Programme (2011-2016) focuses on energy saving and energy efficiency, wind energy, photovoltaic, solar technology, bio-energy, and nuclear fusion. The annual volume of R&D funding through this program -which targets both firms and public research organizations- is more than 0.8 billion € (BMWi 2016). There are no large-scale voluntary agreements on energy saving or energy efficiency on a cross-industry level in Germany, though individual industries such as the chemical industry or the automotive have been following such an approach.

#### *Austria*

Energy always ranked high on the Austrian policy agenda for at least three reasons. First, energy intensive sectors have a long history (e.g., metal producing and processing, cellulose and paper) and relatively high share in manufacturing production. This relates to the second point of a particularly high share of renewable energy from hydraulic power, which traditionally provided a comparative advantage to energy intensive production. The advantage of hydraulic power resources also relates to the third characteristic of a longstanding voluntary ban on nuclear energy, which is still rare among the industrialized economies.

A broad set of policies addresses the objective of increasing energy efficiency. To begin with, the new *Energy Efficiency Law* (Republik Österreich, 2014) is the focal point of Austria's regulatory approach in this area. It came into force at the beginning of 2015, adopting EU guidelines that demand energy efficiency gains of 20 percent until 2020 (relative to 2005). It aims for a combination of regulatory rigor and dynamic incentives through a combination of bureaucratic control and (indirect) market mechanisms. At its core, energy suppliers (except small ones) must prove concrete measures to achieve annual efficiency gains of 0.6 percent relative to their previous year's total energy sales. These efficiency gains may originate either from their own operations or from its customers and depend on the ratio of energy inputs to output (i.e., not on total energy use). Missing the target triggers a compensatory penalty, which is paid to a fund that promotes energy saving activities.

While energy using firms are not directly charged for missing the target, they are allowed to sell their efficiency measures to their energy supplier. Similarly, there is no regulatory protection against suppliers discriminating prices to the disadvantage of firms that cannot offer such savings. The law thus anticipates positive and negative market incentives, which feed back to the energy using firms and will be determined by the supply and demand for energy efficiency measures. In addition, the law commands large companies either to install a

proper energy management system, or to have an energy audit every four years. Due to legal proceedings instituted by opponents of the law, uncertainties about the details of implementation maintained for most of the year. These uncertainties mainly concerned the eligibility of measures, which must be reported to the Austrian Energy Agency (AEA) as the federal energy efficiency monitor. Many firms regard this an undue bureaucratic burden, affecting a generally negative attitude towards the law.<sup>3</sup>

Different e.g. from recycling activities, the Austrian system provides little scope for broad-scale voluntary agreements in the field of energy efficiency.

The Austrian tax authorities collect taxes and levies on the use of electricity, fossil fuels (petroleum, natural and liquid gas) and coal, which are generally based on physical units ("unit taxes"). Initially introduced for fiscal purposes, their design also reflects the trade-off between ecological motives and industrial policy concerns. From the perspective of environmental economics, taxes have the advantage of providing sustained incentives to reduce emissions down to the last unit (Köppl and Schratzenstaller, 2015). They are economically most effective as a flat rate that applies to the energy content or implied carbon emissions (e.g., Baumol and Oates, 1971). The Austrian system violates both principles, applying different rates that depend on the energy source and kind of use (e.g., power vs. heating fuels) and imposing a ceiling for energy-intensive firms in manufacturing production (Kletzan-Slamanig and Köppl, 2016). In 2004 the ceiling of the energy levy was raised from 0.3% to a maximum of 0.5% of value added. In 2002 the discrimination in favour of manufacturing prompted a continuing legal dispute about whether the ceiling must also apply to other sectors (currently proceeded at the *European Court of Justice*). As a consequence, the energy levy accounts only for 10 percent of the total environmental taxes (most of the latter relate to transportation such as mineral tax and insurance taxes based on engine-capacity). Taken together, environmental taxes amount only to 6 percent of total tax revenues, which is considerably below the EU average (Köppl and Schratzenstaller, 2015).

Austria participates in the EU CO<sub>2</sub> emission trading scheme, which was considerably reshaped for the period 2013 to 2020. While in general, the free allocation of emission permits will continuously decrease and be replaced by competitive auctions, sectors that are particularly exposed to "carbon leakage" remain exempted and will benefit from the undiminished free allocation of emission rights.

Finally turning to public subsidies, targeted programs towards the innovation of new energy related technologies are procured by the *Austrian Research Promotion Agency* (FFG), which is the national funding agency for industrial research and development. The current program for "energy research" is the third in a consecutive series of targeted promotion schemes since 2008. The activities of the FFG are complemented by targeted subsidies for the adoption of energy-saving technologies via the Environmental Promotion scheme that is administrated by the *Kommunalkredit Public Consulting* (kpc).

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<sup>3</sup> This seems to have affected also a negative attitude by many of the (non-)respondent firms in Austria, which erroneously associated the enterprise survey on energy efficiency with the new regulation, or attempts for further policy initiatives.



### 3. Literature Review and Hypotheses

Given the presence of market failures concerning the adoption of environmentally friendly technologies (see, e.g., Jaffe and Stavins 1994), theoretical studies argue that long-term incentives to adopt environmentally friendly technologies are stronger under market-based instruments (e.g. subsidies, taxes) than they are under command-and-control instruments (see e.g. Downing and White 1986, Milliman and Prince 1989). There are at least two reasons for this. First, market-based instruments have dynamic advantages. They tend to give permanent incentives to further decrease the environmental burden of the production process, since any further improvement of the environmental performance yields lower costs in the form of permits that can be sold, subsidies that can be received, or taxes that can be saved (see e.g. Jaffe and Stavins 1995, Cleff and Rennings 1999). Secondly, market-based instruments allow for a cost effective response to environmental issues, the firm can choose the most cost-effective way to improve its environmental performance according to its characteristics. In contrast, environmental standards and regulations allow for a less flexible firm response and have adverse dynamic characteristics, since once a standard or the regulatory requirements have been satisfied, there are hardly any incentives to further adopt newer technologies to abate contamination (Jaffe and Stavins 1995).<sup>4</sup>

Voluntary agreements are a third type of instruments to pursue the goal of more environmentally friendly production processes<sup>5</sup> (Cleff and Rennings 1999, Croci 2005, Veugelers 2012). They can be individual agreements or collective or branch agreements. Voluntary agreements share the dynamic advantages of market-based instruments; however, they are even more flexible, which contributes to efficiency and effectiveness and they can be applied to a variety of circumstances taking into account local and branch peculiarities. Given these advantages from a point of view of a policy maker, it is still questionable “why firms should enter into such agreements”. Croci (2005, pp. 11) suggests a number of reasons. For instance, firms want to avoid stricter regulation (see also Rondinelli and Berry 2000, Florida and Davison 2001), or lower the adaption costs through better information which results from the negotiations to reach an agreement, they can gain reputation and most importantly they obtain their flexibility in choosing the adaptation process. Although these aspects point at the superiority of voluntary agreements, their effectiveness might suffer, since voluntary agreements does not necessarily involve all polluters and enforcement is usually less strictly. Due to their cooperative nature and their flexibility, it is likely that such agreements—at least in markets with a relatively low diffusion rate of green energy technologies—essentially support the diffusion of such technologies.

Market demand for environmentally friendly produced products is considered as a fourth type of incentive. Arguing from the perspective of the focal firm, market-based instruments, regulation, and voluntary agreements are strongly related to its cost side, whereas the demand side is largely ignored in studies about technology adoption, although it should be one of the most effective forces for profit oriented firms, since it provides full technological flexibility and low transaction costs. Hence, market demand (policy driven or not) for

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<sup>4</sup> See also Stucki and Woerter (2016) for an overview of theoretical arguments in favor of market based policies.

<sup>5</sup> A comprehensive categorization of voluntary agreements includes voluntary public schemes, negotiated agreements, unilateral commitments recognized by the public administration, unilateral commitments, third party initiatives, and private agreements (Croci 2005, p. 7)

environmentally friendly produced products should be an effective factor for adopting environmentally friendly technologies.

Following the literature (see, e.g., Cleff and Rennings 1999) it is clearly that both, costs and the demand factor are important for the adoption decision of a firm. However, it is difficult to identify, which policy instruments are most effective in encouraging the adoption, since the design of the instruments, the characteristics of the regulator (Requate and Unold 2003), and the characteristics of the affected firms play a role as well (Crocchi 2005, Jaffe and Stavins 1995, Magat 1978, Malueg 1989, McHugh 1985). However, given that only regulation shows serious theoretical adverse characteristics, we want to formulate our first hypothesis:

*H1: Regulation is less effective than market-based policies, voluntary agreements, or demand to increase the propensity of technology adoption*

In order to observe far reaching positive environmental effects of technology adoption is not sufficient that energy-related technologies are adopted, it is essential that such technologies also diffuse within the firm (intra-firm diffusion) or to express it differently, that they are used intensively. But how policies can also increase the intensity of adoption? Actually we could assume that the expected policy effect resembles the effect for the adoption. However, this is not necessarily the case for at least two reasons.

First, the benefits from the environmentally friendly policy regime are fully exploited with installing a specific technology, e.g., an end-of-pipe solution if the regulation requires it, and no further incentives are provided. The same is true for voluntary agreements. Once the condition of a such an agreement are met, and the environmental friendliness of a new, e.g., production technology, is secured and communicated, e.g. with a label, then there might be no further incentives to invest more in environmental friendly technologies (intensity of adoption). However, this is not necessarily the case with taxes/levies or subsidies. Those instruments potentially provide dynamic advantages, meaning that the benefits increase proportionately with the intensity of adoption. This brings us to the second reason.

Second, a proportional increase of benefits resulting from the policy framework is likely to be insufficient to induce further environmentally friendly investments, since the costs for additional energy savings increase disproportionately, similar to abatement costs. Kuik et al. 2009 in a meta-analysis of marginal abatement costs identified a very skewed distribution meaning that the median abatement cost level is significantly lower than the means of abatement costs. This indicates that the marginal costs increase disproportionately unless technological development significantly lowers them (Baker et al. 2008). Hence, firms have to make disproportionately greater financial efforts to reduce energy consumption beyond a level that is suggested by the dominant technology and without incentives resulting from an improved design of the environmental policy (Hemmelskamp 1997, Kerr and Newell 2003) or other economics factors, like the market structure, technological opportunities, demand factors, or the energy intensity, the focal firm is unlikely to improve its environmental performance by increasing its investments. However, the policy effects on investment intensity are not necessarily positive. Zhao (2003) confirmed the results of Milliman and Prince (1989) and Jung et al. (1996) stating that market based policies, like emission pricing, can even lower the incentives to intensively invest in abatement technologies or—in our case—energy-saving technologies, since tradable permits should

become cheaper the more firms adopt environmentally friendly process technologies. However, under investment uncertainty, specific types of policies can reduce investment incentives. Zhao (2003) found that emission charges are likely to reduce investment incentives, even greater than under tradable permits. Our second hypothesis reads as follows:

H2: The policy effects for higher investments in green-energy technologies are lower than for the adoption propensity.

*Empirical studies on adoption propensity (inter-firm diffusion)*

The empirical evidence vastly confirms H1. Kerr and Newell (2003) investigated the technology adoption behavior of refineries during the lead phasedown in the USA and they found that the adoption propensity of refineries with low compliance costs was greater under market-based lead regulation than under performance standards. Jaffe and Stavins (1995) investigated the adoption decision for thermal insulation technologies under different policy regimes; these are taxes, subsidies, and technology standards. They found that the technological cost effect is three times larger than the adoption effect of energy savings over the whole lifetime of the investment. Hence, it is comprehensible that subsidies exert a much higher positive effect than taxes on the adoption propensity. Quite contrary to subsidies, the building codes (command-and-control instrument) did not contribute to the diffusion of insulation technologies. Since the observed building codes did not make any significant differences to the existing building practices, the authors cannot exclude that more stringent codes might have had an effect.

Switching to studies based on European data, Van Leeuwen and Mohnen (2015) used Dutch survey data from four different sources—environmental cost survey, the energy use survey, the community innovation survey, and the production statistic survey—to investigate the policy effects for the adoption of environmentally friendly process innovation. Applying a structural model in the spirit of the CDM (Crepon, Mairesse, Duguet 1998) model, they found that levies and regulation are positively correlated with environmentally friendly investments in process innovation (0/1 decision). However, due to the dependent variable (eco investments 0/1) it was not possible to insert subsidies in the adoption equation, which might drive the observed effects of the other policy variables (levies, regulation). Cleff and Rennings (1999) used German data and investigated the policy effect on “innovation integrated measures on the process level”. They found evidence that the so-called “soft” factors are very supportive to environmentally friendly process innovations, whereas among other state regulation did not show any effect. The term soft-factors refers to voluntary agreements and informational instruments. Frondel et al. (2007) also investigated environmentally friendly innovation decisions based on survey data for Germany. Their results suggest that the adoption of cleaner production technologies tends to be market driven and not so much by regulatory measures. Similarly, Horbach et al. (2012) investigated the influence of policies on firms’ decision for adopting environmentally friendly process innovations. They identified technologies according to their environmental impact; for instance, to save energy or to reduce CO<sub>2</sub> emissions. Concerning energy-related technologies they found that self-commitment (voluntary agreements) and demand for environmentally friendly produced products show a significant and positive effect; regulation and even subsidies were not significantly related to energy-related processes innovations.

Veugelers (2012) used adoption motives as a measure of policy affectedness. Based on Flemish CIS-data she assessed the responsiveness of firms to environmentally friendly policy interventions. Besides the generation of green technologies, she also assessed the effect of the policies on the propensity to adopt environmentally friendly technologies. She found that regulations/taxes show a larger effect than subsidies and voluntary industry codes and agreements are important drivers for introducing environmentally friendly technologies.

Demirel and Kesidou (2011) used data from 289 UK firms stemming from the Government Survey of Environmental Protection Expenditure by Industry' in years 2005 and 2006. They measured the use of cleaner production technologies by their investment level. Hence they investigated both the effect of policies on the adoption decision (0/1) and on the intensity of adoption (see below). Neither regulation nor the market based instrument (taxes) showed a significant effect in the full model specification.

#### *Empirical studies on the level of investment (Intra-firm diffusion)*

The empirical evidence about the relative inducement effect of several environmental policies for the *intra-firm* diffusion of green energy technologies is relatively scarce.

Van Leeuwen and Mohnen (2015) could use a comprehensive Dutch data set (see above) and they did not only investigate the 0/1 choice for process-integrated, environmentally friendly investments, they also investigated the policy effects on the investment intensity using the CDM (1998) framework. The 0/1 choice and the intensity effects have been estimated simultaneously taking into account potential selection issues. They found that subsidies and regulation show a significant effect for investment intensity (Leeuwen and Mohnen 2015). Moreover, energy intensity is also significant and positively related with the dependent variable.<sup>6</sup>

Stucki and Woerter (2016) based on Swiss survey data could not observe the relationship between different type of policies and non-political, voluntary agreements and the adoption decision (0/1). However, they could observe the effect of different instruments on the number of environmentally friendly, energy-related technologies along the value added chain of a firm. Considering potential selection issues they found that taxes and regulation are the most effective policy instruments for increasing the intra-firm diffusion of environmentally friendly, energy-related technologies. Taking into account non-political motives, it turned out that "voluntary agreements" do significantly increase the adoption intensity and that they are even more effective than policy measures. Hence, taxes, regulation, and voluntary agreements are the most important motives for the intra-firm adoption of green energy technologies.

Like mentioned above, Demirel and Kesidou (2011) used firm level information about 289 UK firms and measured the level of investments into integrated cleaner production technologies. In their main estimations neither environmental regulation nor environmental taxes significantly increased the investments in cleaner production technologies.

Given these empirical results so far, we get the impression that the observed results strongly depend on the measurement of policies, the number of types of policies controlled for in the model, and the measurement of

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<sup>6</sup> However, if they lag the non-policy covariates by two periods the effect of regulation gets insignificant. (see earlier version of the paper: Leeuwen and Mohnen 2013).

the intensity variable. Leeuwen and Mohnen (2015) for the Netherlands and Demirel and Kesidou (2011) for the UK measured the intensity of the adoption of process-integrated technologies by the size of investments and Stucki and Woerter (2016) for Switzerland counted the number of different technologies adopted to measure the intra-firm diffusion of energy-related technologies and all three studies present quite different results. Hence, the empirical findings concerning H2 are mixed and the measurement issues gain in importance.

#### 4. Survey and data description

We designed a particular questionnaire in order to collect the data necessary to test the above mentioned hypotheses.<sup>7</sup> This questionnaire laid the basis for a comprehensive survey with the topic “creation and adoption of energy-related technologies”, carried out simultaneously in three countries (Austria, Germany, and Switzerland) in 2015. It was sent to 5789 Swiss firms (KOF-Enterprise Panel), 6374 German firms (ZEW-Enterprise Panel) and 7091 Austrian firms (WIFO Enterprise Panel). The representative firm samples for the respective countries comprise the whole manufacturing, service, and construction sector. It is a stratified random sample, whereas stratification takes place on the two-digit industry level and on three industry-specific firm size classes (with full coverage of large companies)<sup>8</sup>.

The response rates are quite different across the countries. The survey yielded valid information for 1815 firms (31.4%), 2321 (36.4%), and 539 firms (7.6%) for the countries Switzerland, Germany, and Austria respectively. Given the very demanding questionnaire the response rates for Switzerland and Germany are satisfying, whereas the return from Austrian companies was disappointing for various reasons.<sup>9</sup> However, a comprehensive recall action in all three countries ensures that we received a sufficient large number of answers covering all industries and all firm size classes according to the sampling scheme (cells). Only for Austria some cells could not be filled.

Due to missing values for some questions the estimations presented in this paper are based on 3465 observations. However, due to specific questions referring only to a subgroup of firms, the number of observation can be lower (see estimations below).

The questionnaire contains questions about some basic firm characteristics (sales, exports, employment, investment and employees' education). Moreover, it contains questions about the importance of energy-

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<sup>7</sup> Publicly available data is not sufficient to identify the relative effects of different policies. It needs survey data for at least two reasons (see Stucki et al. 2016). First, to get a complete picture, all relevant policies would need to be identified, which is hardly possible as they can be firm/sector- and technology- specific. Second, also the stringency of single policies matters, which is difficult to measure and hardly available from public sources (Shadbeigian and Wolvertson 2010, Xing and Kolstad 2002). The difficulty arises, since different policies typically cover different firms or policies may exist at multiple levels (e.g. federal and local), and monitoring and enforcement are imperfect (Millimet and Roy 2015).

<sup>8</sup> See Arvanitis et al. (2016) for the full sample information.

<sup>9</sup> In part, the lower return in Austria was expected, since different from the German and Swiss samples, we had no established innovation panel to rely on. Return rates for so called “cold” panels, where all firms must be contacted *de novo* are generally lower. However, we also experienced unanticipated problems, which relate to the introduction of a new energy efficiency law in Austria (see the previous Section).

related factors, like energy-related taxes and levies, energy-related regulations, energy-related voluntary agreements, public subsidies, and demand related factors. Moreover, we have information about the fluctuation of energy prices and (feared) bottlenecks in energy supply. A unique characteristic of the questionnaire is that all firms needed to answer such policy related factors, independently if they adopted energy-relevant technologies or not. This has the advantage that we can identify the meaning of the policy environment for all firms and not only for firms that have already adopted environmentally friendly, energy-related technologies, like it is usually found for policy related questions in the CIS (Community Innovation Survey) type of questionnaire. Hence, we can contrast (for the first time) the effectiveness of policy related factor for the adoption stage (inter-firm diffusion) with their meaning for the intensity stage (intra-firm diffusion).

Table 1 presents the variable definitions and some descriptive information for the variables included in our main estimations. 50% of the responding firms adopted environmentally friendly, energy-related technologies and on average they spent around 39000 Euros for the adoption of such technologies.<sup>10</sup> On average firms perceive taxes (1.71) as the most relevant energy-related policy followed by regulations (1.49) and public subsidies (1.46). Firms also perceive high/volatile energy prices as a relative important characteristic of their energy-related environment. 54% of our sample firms export, 11% are foreign-owned and 38% have R&D activities. The competition intensity—measured by the number of principal competitors—is moderate on the means level; firms tend to operate in markets with less than 15 competitors worldwide. The energy costs are on average about 115000 Euros, however, the distribution seems to be rather skewed, since there are few firms with rather high values. Adoption of environmentally friendly, energy relevant technology is no topic or has not been discussed for 39% of the firms.

Table 2 presents some country specific information. First, we see different adoption propensity ranging from about 40% in Switzerland to 56% in Austria. Moreover, we see that taxes are perceived as more relevant in Germany than in the other countries, voluntary agreements are of relatively high relevance in Switzerland, and public subsidies is the dominant policy factor in Austria.

Correlation coefficients for the main model variables are presented in Table 3. Most importantly we see that the dependent variables are significant and positively related with the energy-relevant factors, whereas the correlation coefficients tend to be higher for the adoption variable than for the investment variable (except regulation). Among the policy relevant factors, we also see positive and significant correlation with relatively high coefficients between demand and subsidies, subsidies and voluntary agreements, voluntary agreements and regulation, and regulation and taxes. Hence, the correlations indicate that it is important to insert all factors in the model to identify the effects precisely.

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<sup>10</sup> These are unweighted figures; for the representative figures please refer to Arvanitis et al. 2016.

## 5. Econometric framework

In order to analyse the effects of different types of policies on the inter-firm and intra-firm diffusion of environmentally friendly, energy-related technologies, respectively, we refer to an econometric framework in the spirit of Battisti et al. (2009), which is an extension of Karshenas and Stoneman (1995). Such models have been applied, e.g., by Hollenstein and Woerter (2008) for E-commerce adoption, by Arvanitis and Ley (2013) in terms of inter- and intra-firm diffusion of energy-saving technologies, or by Stucki and Woerter (2016)<sup>11</sup> concerning the intra-firm diffusion of energy-related technologies.

According to Battisti et al. (2009), the first use (inter-firm diffusion) of a new technology and the intensity of its usage (intra-firm diffusion) in time  $t$  by firm  $i$  in industry  $j$ ,  $D_i(t)$ , are determined by five categories of variables: First, a vector of characteristics of a firm  $R_i(t)$  and its environment  $R_j(t)$  reflecting rank effects<sup>12</sup> referring to, e.g., energy intensity, competition, qualification of the employees, or demand. Secondly, the extent of industry usage of new technology  $SO_j(t)$  to capture inter-firm stock and order effects<sup>13</sup> (i.e., market-intermediated externalities). Thirdly, epidemic effects<sup>14</sup> (i.e., learning and network non-market intermediated externalities) reflecting either the firm's own experience with the new technology  $E_i(t)$ , often proxied by the time since the firm's first adoption, or the experience gained from observing other firms  $E_j(t)$  (often measured by the extent of technology diffusion among similar firms in time  $t$ ). Fourthly, the expected adoption cost of a unit technology  $P_i(t)$  that is constituted by two parts: one common to all firms, e.g., the price of a new, energy efficient technology; and a second one reflecting firm-specific adjustment and installation costs. Fifthly, in accordance to the particular conditions of the introduction of green energy technologies in Switzerland (as in many other countries), also elements of the literature on induced innovation and technology diffusion (see, e.g., Binswanger 1974) are taken into consideration. The diffusion of green energy technologies can be positively influenced (a) through increases of energy prices and/or taxes (see, e.g., Linn 2008 and Jacobs et al. 2009) and (b) through public regulation and/or public incentives (subsidies), and/or "voluntary agreements" to use green energy technologies (see, e.g., Popp et al. 2009, Croci 2005). We consider a vector  $IA_i(t)$  of variables that capture the influence of such factors (inducement effects). We therefore arrive at the following equation that we use for estimating the adoption models:

$$D_i(t) = f\{R_i(t), R_j(t), SO_j(t), E_i(t), E_j(t), P_i(t), IA_i(t)\} \quad (1)$$

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<sup>11</sup> Stucki and Woerter (2016) provide a very similar econometric framework, however their estimations are limited to intra-firm diffusion and they could not—due to the lack of policy information—compare policy effects for inter- and intra-firm diffusion or apply this framework simultaneously to different countries.

<sup>12</sup> Rank effects refer to firm heterogeneity that could lead to differing returns to adoption and consequently to different adoption behavior (Davies 1979, Ireland and Stoneman 1986).

<sup>13</sup> Stock and order effects refer to market-intermediated externalities either due to early-mover advantages (order effect) or lower adoption costs due to a higher number of firms utilizing a technology (stock effect) (Battisti et al. 2009).

<sup>14</sup> Epidemic effects refer to learning and network effects either from the firm's own experience gained from using a technology or the knowledge gained from observing other users of the technology (Hollenstein and Woerter 2008, Battisti et al. 2009).

For the empirical implementation of the model, we follow as far as possible Arvanitis and Ley (2013) and Stucki Woerter (2016). Firm-specific *rank effects* are measured by (a) the firm's number of employees, (b) gross physical investments, (c) the qualification level of the employees, (d) R&D activities, (e) export activities, (f) foreign ownership, and (g) the relevance of energy-related technologies for the focal firm. The R&D activities and the qualification level of the employees also control for the firms' absorption capacity, which is important as not each company has the same conditions to deal with the adoption of new energy-related technologies. Moreover, we inserted the control variable for the relevance of energy-related technologies for the focal firm controlling for firms without a relevant technological base or a non-technological orientation and, hence, such technology issues do not apply and consequently have not been discussed internally. Rank effects as to the firms' market environments are measured by (a) the intensity of competition, (b) the energy environment characterized by high/volatile energy prices and energy shortage, (c) industry affiliation, and (d) country dummies. Based on cross-sectional data it is hardly possible to separate *epidemic effects* from *stock and order effects*. Hence we measure a net effect of the two by including the mean of adopted technologies within the firm's two-digit industry (without the focal firm).<sup>15</sup> Based on the survey results the *Adoption costs* could not be measured effectively, since the perception of obstacles frequently increases with adoption activities and consequently is clearly endogenous. Information about market prices of technologies and internal adjustment costs are not available for the sample of firms we could use. Finally, in order to capture *inducement effects* we control for (a) the firm's energy costs and most importantly for this paper (b), the firm's political environment, which is measured by variables referring to regulation, subsidies and energy taxes. Furthermore, we can distinguish these standard policy factors from alternative drivers of energy-related technology adoption, we control for (d) "voluntary agreements", and (e) the demand for environmentally friendly produced products. See Table 1 to Table 3 for the variable definitions and descriptive statistics, respectively.

An important feature of existing empirical investigations about policy induced adoption based on survey data is that the meaning of the policy environment of non-adopter is not observed. For instance, in the CIS the policy effects are usually identified as a motivational question referring only to firms that have already adopted such technologies, e.g. "how important were the following factors in driving your decisions to introduce innovations with environmental benefits?" Consequently, information about the policy affectedness of non-adaptors is missing meaning that such data sets lack policy information for firms that did not adopt an environmentally friendly technology although they are potentially exposed to the same policy pressure than adopting firms. For the study at hand we designed a specific set of questions that allows for policy information for non-adaptors as well. Hence we can compare policies that drive the adoption (inter-firm diffusion) with policies that drive the intensity of adoption (intra-firm diffusion).

Although we have policy information for adoptors and non-adoptors, we can only observe investments in energy-related, environmentally friendly technologies (our dependent variable), if a firm adopted such a

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<sup>15</sup> In order to separate the epidemic effects from other industry-specific effects, we add industry fixed effects to the model.



technology, and we do not observe the investment behavior if such technologies have been not adopted.<sup>16</sup> Moreover, we have an interest in the parameters of the selection equation and of the intensity equation. Hence, we apply a sample selection estimator which is formulated according to Heckman (1979) and Amemiya (1985).

In econometric terms we face the following problem:

$$y_1 = x_1\beta_1 + u_1 \quad (1)$$

$$y_2 = 1[x\delta_2 + v_2 > 0] \quad (2)$$

Let  $y_1$  be our investments in adoption of environmentally friendly, energy-related technologies and  $y_2$  is the binary variable indicating the adoption of such a technology;  $x$  and  $y_2$  are always observed and  $y_1$  is only observed if  $y_2$  equals 1.  $u_1$  and  $v_2$  are independent of  $x$  and have zero mean, whereas  $v \sim \text{Normal}(0,1)$ ;  $x_1$  is a strict subset of  $x$ ; and  $E(u_1 | v_2) = \gamma_1 v_2$

Basically we could estimate (1) consistently and efficiently if the (here) unobserved  $\gamma_1 = 0$ , indicating that we do not have a selection problem. However, since we cannot be sure that this is the case, we follow the Heckman (1979) procedure, which allows us to estimate

$$E(y_1 | x, y_2 = 1) = x_1\beta_1 + \gamma_1\lambda(x\delta_2)$$

where  $\lambda(x)$  is the inverse mills ratio. Here,  $\gamma_1$  can be observed by inserting the inverse mills ratio in the model and if it is zero, equation (1) does not suffer from a selection bias and the coefficients are consistently and efficiently estimated (see Wooldridge 2010, pp. 803).  $\delta_2$  is available from the first stage probit estimation, which is only consistently estimated if  $x$  contains one variable that affects  $y_2$  –the selection equation–but does not have a partial effect on  $y_1$  (see Wooldridge 2002, p. 562). In the paper at hand we can use the epidemic variable in the selection equation as the necessary exclusion restriction; it is significantly positively related to the adoption propensity ( $y_2$ ) and has no effect on  $y_1$ .<sup>17</sup>

A potential problem is the possible endogeneity of some of the right-hand variables that would imply inconsistent estimates. Endogeneity might arrive not so much from the policies per se, since the design of the policies is clearly beyond the influence of a single firm and they likely perceive them as an exogenous shock, however, the endogeneity issue might result from the “subjective” evaluation of the importance of the respective policies. We asked the firms to assess how important (on a 3 point Likert-scale) are taxes, subsidies, voluntary agreements, regulation, and demand for them. These assessments might be correlated with some unobserved firm factors that can bias our coefficients. However, since a broad set of observables that generally affect the firms’ adoption activities is included in the estimation equations besides the policy variables<sup>18</sup>, our

<sup>16</sup> A firm might have invested in clarifying a potential adoption and finally did not do it, since the adoption project failed.

<sup>17</sup> In order to estimate the heckman procedure we use the heckman command as implemented in STATA 13 with heteroscedasticity robust standard errors; we use the full maximum likelihood version of the estimator.

<sup>18</sup> We control for unobserved heterogeneity on the sector level (2-digit level). Moreover, we have a very comprehensive control vector correcting for most of the factors that might influence the assessment; such factors are the energy intensity of the focal firm, its R&D activities, the education level of the employees,

main results should at least not be affected by an omitted variable bias. We do not see why the used policy measures should systematically share a common unmeasured cause with the firms' adoption intensity.<sup>19</sup> We thus expect that the policy variables affect the firms' adoption intensity directly and endogeneity is not a main concern. However, we do not claim causal relationships.

We are not only interested in the policy effects for the adoption propensity (inter-firm diffusion) and the level of investments of adoption (intra-firm diffusion), we are also interested, if there are differences among the participating countries. In order to identify differences, we interacted all covariates with the country dummies respectively. This has the advantage that we directly observe, if the detected differences are significant.

## 6. Results

Table 4 presents the main results of our estimations. The results of both stages of the heckman estimation are presented in column 2 and 3.

### *Adoption propensity (Inter-firm diffusion)*

Most importantly, we see that taxes, voluntary agreements, public subsidies, and demand significantly induce the adoption of environmentally friendly, energy-related process innovations (green energy technologies); firms that identified such factors as important are significantly more likely to adopt such technologies. The results for the control variables in the model indicate that the adoption propensity is higher for larger firms, firms with R&D activities, and firms with greater gross tangible investments. The epidemic variable is also significantly and positively related with the adoption propensity of the focal firm. The results also unveil that (feared) bottlenecks in energy supply significantly decrease the adoption propensity and forces firms to stick to traditional technologies and that high/volatile energy prices urge firms to adopt green energy technologies. Referring to the econometric framework presented above we see that firm specific rank effects and epidemic effects are important, however, the inducement effects resulting from the policy environment appear to be very important for the adoption propensity; here, only regulations (including CO2 certificates) do not show a significant effect indicating that the regulatory requirements have been already fulfilled by the firms before the period under investigation, hence, lacking any further incentives for technological improvements. This clearly points at the "dynamic" disadvantages of regulations, presented in the literature review; regulations usually do not require to adopt the best available technological solution; once the requirements are fulfilled no further environmentally friendly activities can be expected. Hence, we cannot reject H1 meaning that regulations are indeed less effective than market-based policies, voluntary agreements, or demand to increase the propensity of green energy technology adoption.

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foreign ownership, size, basic relevance of environmental issues, intensity of competition, export activities, and other investment activities.

<sup>19</sup> Even more so as we are primarily interested in the effects of the different policy types relative to each other.

### *Level of investments (intra-firm diffusion)*

The Heckman estimation presented in column 1 (intensity) and column 2 (selection) in Table 4 shows that both equations are independent and that the intensity equation is not affected by the selection issue; the Wald test on independence of equations ( $\rho = 0$ ) is insignificant.

The most striking result is that all but one proxy for energy-related (policy) factors are insignificant, indicating that the current political framework and policy related factors are less relevant for the firms' decision to increase its investment in green energy technologies (intra-firm diffusion); this is in stark contrast to the results for the adoption decision presented above. Only the importance of subsidies is significant and positively related with the amount of investments.<sup>20</sup> Referring to H2, our results clearly show that the policies are less relevant for the amount of investments in green-energy technologies rather than for the adoption propensity.

Moreover, we see that the energy costs are also significant in the intensity equation signalling that firm specific energy-related factors are more important than policy inducement for the amount of investments. It is also remarkable that investments tend to increase in an energy environment that is characterised by high/volatile energy prices, whereas feared energy shortage does not affect the amount of investments.

### *Country comparisons<sup>21</sup>*

Given the different institutional framework in the investigated countries (see above), it is plausible to assume that the investigated types of policies show different effects. And in fact we find that taxes are significantly more effective for the adoption decision of a firm in Germany than in Austria and Switzerland (Table 4, column 6 and 7). We also see differences in terms of voluntary agreements, which are significantly less effective in Austria than in Germany and Switzerland. To the contrary, public subsidies are more effective (important) in Austria and demand related factors for environmentally friendly produced products tend to be more effective in Switzerland compared to Germany. Concerning regulation, we do not see significant differences across countries.

The results are quite different for the amount of investments (intra-firm diffusion). Public subsidies are significantly more effective in Germany and Austria than in Switzerland. We do not detect any differences for all other policy related factors.

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<sup>20</sup> Please note that the perception of subsidies as a stringent policy measure does not „mechanically“ increase the amount of investments.

<sup>21</sup> The estimations for the single countries are presented in the Appendix Table A1. Basically the general results presented above hold for all three countries with few exceptions. Concerning the propensity: voluntary agreements are significant and negative for Austria and taxes are only significant and positive for Germany. Concerning the intensity, subsidies are not significant in Switzerland.

## EXTENSIONS

### *Marginal effects*

Although we cannot claim to present causal effects, we want to give an impression about the size of the effects of the observed policies and policy related factors; Table 5 presents the marginal effects. The probability of a randomly chosen firm to adopt any green energy technology—in our sample—is 49%. This figure fluctuates between 40% in Switzerland and 56% in Austria. Moreover, we see that the adoption probability significantly increases with the relevance of taxes (47%-53%), voluntary agreements (48%-58%), public subsidies (44%-68%) and demand (47%-58%), whereas public subsidies are related with the relatively strongest increase in the adoption probability. There are country differences. The relatively largest increase in adoption probability results from public subsidies in all three countries. Voluntary agreements and demand are increasing the adoption propensity in Switzerland by 21%-points and 23%-points, respectively. Taxes increase the adoption propensity in Germany by 13%-points and demand shows a relatively strong effect in Austria (+27%-points).

### *Technology specific effects and certified management systems*

Table 6 presents the results for specific types of green energy technologies and energy saving certified management systems (e.g. environmental certification ISO 140001, Energy-management ISO 50001, environmental-/energy-target declaration, periodical environmental-/energy-reports). We included the certified management systems to the simultaneous estimation procedure, since previous literature shows that they are immediately related to technology adoption. For instance, Frondel et al. (2007) found that organizational measures are very important for the adoption of environmentally friendly process innovations. Also Khanna et al. 2009 presents evidence for a strong and significant relationship between totally quality management and the adoption of pollution prevention technologies.

Demand related factors are important for the adoption of all identified technologies, whereas the adoption of energy saving technologies in the field of production are also significantly promoted by taxes and public subsidies. Concerning building technologies, the adoption stimulating effects of voluntary agreements, subsidies, and demand are significant. Public subsidies and demand essentially drive the adoption of technology to produce energy from renewable sources.

We also can compare the effects of policy related factors for green technology adoption with firm behaviour related to the introduction of energy saving certified management systems. Management systems are essentially driven by taxes, voluntary agreements, and subsidies. Demand related factors do not play an important role for management systems, which is in stark contrast to green technology adoption.

Obviously, national promotion plans appear to be relatively ineffective in the transportation sector. Public subsidies and demand related factor appear to be effective independent of the type of technology.

## 7. Conclusions

We have seen a significant increase in the empirical literature about the adoption of environmentally friendly technologies over the last years. Nevertheless, there are some important blind spots that have not been

addressed adequately, not at least due to the lack of firm-level data. First, we have still an insufficient understanding of the effect of environmental policies (taxes, subsidies, and regulations), voluntary agreements, and demand related factors, on the adoption of green energy technologies. Moreover, we know too less about their effects on the intensity of technology use and how they impact the adoption of non-technical measures (certified management systems). Second, policy makers tend to apply best-practice from other countries. However, it is not sure that, e.g., a CO<sub>2</sub> tax or a feed-in tariff has the same effects in Germany and in Switzerland; the institutional framework matters, and should be seriously considered.

In the study at hand we try to address those issues by simultaneously estimating the policy effects on the propensity and intensity of adoption of green energy technologies. Moreover, we compare the policy effects for different technologies and non-technological measures (management systems) in a multivariate estimation setting and we simultaneously investigate country specific differences concerning the effects of different types of policies for the adoption behaviour.

The results are based on a comprehensive data set stemming from a firm-level survey in three countries (Austria, Germany, and Switzerland) conducted at the same point in time and based on an identical questionnaire (see data section). The results reveal that the current policy framework in all three observed countries is partly effective for the adoption of such technologies and non-technical measures and it is ineffective in terms of the intensity of adoption (intra-firm). Firm specific characteristics drive intra-firm adoption whereas primarily voluntary agreements and demand related factors as well as subsidies and taxes drive the propensity of adoption (inter-firm adoption). Country specific characteristics play a significant role in terms of policy effectiveness. Taxes are more effective in Germany and demand related factors are more effective in Switzerland. Public subsidies are more effective in Austria. The results are different for the investment intensity (intra-firm diffusion). Here we see that public subsidies tend to be more effective in Austria than in Switzerland. However, in order to identify the efficiency of policy instruments, we would have to include the economic costs of policies which is beyond the focus of this study and must be left for future investigations.

#### *Policy conclusions*

From the results of this investigation we can draw the following policy conclusions. First and most importantly, the results show that the tested types of policy instruments effectively stimulate the adoption of green energy technologies and energy management systems, however, they do not have any effect on the intensity of adoption. Intensity matters, though, if we want to significantly decreasing the environmental burden. Only the importance of subsidies is significantly related to the amount of investments. This implies that policy maker should consider the disproportionate increasing cost for adopting green energy technologies. Dynamic policies like taxes, usually yield proportional returns which do not compensate for disproportionately increasing costs.

Apart from that, the energy costs and high/volatile energy prices are raising the investments. Given that we consider taxes as a policy instrument in our analysis, both factors (energy costs and volatile energy prices), are beyond the immediate influence of national policy makers and would require a more global coordination. Hence, our study identifies a lack of policy designs promoting higher amounts of investments in green energy

technologies. Second, demand for energy efficiently produced products and services is an important factor for the propensity of green energy technology adoption. Policy instruments that raises awareness towards energy-efficient behaviour among consumers and policies that inform consumers about the energy-efficiency of production processes, hence, is an effective stimulus for the adoption of green energy technologies in the firm sector. This effect is observed in all three countries and seems to be rather independent of the respective institutional framework, however, demand factors tend to be more effective for Swiss firms. Fourth, voluntary agreements and standards are significantly related to the adoption of green energy technologies and the adoption of energy management systems. Voluntary agreements and standards are partly motivated by avoiding public regulations so that one may suspect that the threat of a potential public intervention to be the underlying cause for their effectiveness.

Policy maker relying on a portfolio of different types of policies including subsidies and demand related factors are on the save side in terms of their general effectiveness. Taxes and voluntary agreements are also overall effective but they show some technology specific patterns, which can be due to the lack of initiatives related such instruments. Given the current institutional framework in the respective countries, subsidies are more effective in Austria, taxes are more effective in Germany, and demand related factors are relatively more effective in Switzerland. This result can have two interpretations. First, subsidies in Austria and taxes in Germany are significantly higher than in Switzerland and consequently they are more stringent and effective. This also implies that such policy measures are broadly accepted by the firms. Second, these policies are better designed in these countries and they better consider the particularities of the firms. Both reasons cannot be tested in this framework and must be left for more detailed policy analyses. However, the main lesson is that such policies are not effective independent of designs and institutional acceptance.

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Table 1: Descriptive information

MAIN VARIABLES	Description	N	Mean	SD	Min	Max
Adoption 0/1 (DEPENDENT)	Adoption of green energy technologies, i.e. technologies that contribute to increase energy efficiency and/or enable the use of energy from renewable resources	3535	0,49		0,00	1,00
Energy investments (ln) (DEPENDENT)	Investments for the adoption of green energy technologies	1621	10,56	2,46	0,69	18,39
Taxes	The importance of energy-relevant taxes and levies for the focal firm	3535	1,71	0,74	1,00	3,00
Regulations	The importance of energy-relevant regulations for the focal firm	3535	1,49	0,68	1,00	3,00
Voluntary agreements	The importance of energy-relevant voluntary agreements or standards in the sector of the firm	3535	1,40	0,63	1,00	3,00
Public subsidies	The importance of energy-relevant subsidies for the focal firm	3535	1,45	0,68	1,00	3,00
Demand	The importance of demand for energy efficiently produced products	3535	1,33	0,60	1,00	3,00
CONTROL VARIABLES						
High/volatile energy prices	The importance of high/volatile energy prices	3535	1,78	0,73	1,00	3,00
Energy shortage	(feared) bottlenecks in energy supply	3535	1,26	0,55	1,00	3,00
Number of employees (ln)	Number of employees	3535	3,91	1,56	0,00	11,63
Export	Export activities	3535	0,54		0,00	1,00
Foreign owned	Focal firm belongs to a foreign firm	3535	0,11		0,00	1,00
R&D propensity	R&D activities of the focal firm	3535	0,38		0,00	1,00
Share graduated employees	Share of employees with a tertiary degree	3535	17,33	22,68	0,00	100,00
Competition intensity	Number of principal competitors in the main sales market of the focal firm worldwide; 1 (1-5 competitors), 2 (6-10), 3 (11-15), 4 (16-50), 5 (50+)	3535	2,57	1,46	1,00	5,00
Energy costs	Energy costs of the focal firm	3535	11,67	2,21	0,51	20,27
Gross tangible investments (ln)	Gross tangible investments	3535	12,25	2,34	3,94	21,92
Epidemic adoption	Share of firms that adopted energy-related technology in the sector of the focal firm (excluding the focal firm)	3535	0,45	0,13	0,00	0,94

Table 2: Descriptive information per country

SWITZERLAND	N	Mean	SD	Min	Max
Adoption 0/1	1584	0,40	0,49	0,00	1,00
Energy investments	600	11,28	2,31	3,73	17,29
Taxes	1584	1,63	0,69	1,00	3,00
Regulations	1584	1,56	0,70	1,00	3,00
Voluntary agreements	1584	1,43	0,65	1,00	3,00
Public subsidies	1584	1,40	0,62	1,00	3,00
Demand	1584	1,31	0,57	1,00	3,00
High/volatile energy prices	1584	1,65	0,69	1,00	3,00
Energy shortage	1584	1,27	0,55	1,00	3,00
GERMANY					
Adoption 0/1	1633	0,55	0,50	0,00	1,00
Energy investments	845	9,89	2,42	0,69	18,39
Taxes	1633	1,79	0,77	1,00	3,00
Regulations	1633	1,43	0,66	1,00	3,00
Voluntary agreements	1633	1,36	0,62	1,00	3,00
Public subsidies	1633	1,49	0,72	1,00	3,00
Demand	1633	1,34	0,62	1,00	3,00
High/volatile energy prices	1633	1,92	0,74	1,00	3,00
Energy shortage	1633	1,24	0,55	1,00	3,00
AUSTRIA					
Adoption 0/1	300	0,56	0,50	0,00	1,00
Energy investments	165	11,34	2,25	3,91	17,27
Taxes	300	1,67	0,75	1,00	3,00
Regulations	300	1,44	0,66	1,00	3,00
Voluntary agreements	300	1,40	0,63	1,00	3,00
Public subsidies	300	1,61	0,75	1,00	3,00
Demand	300	1,37	0,63	1,00	3,00
High/volatile energy prices	300	1,76	0,73	1,00	3,00
Energy shortage	300	1,28	0,58	1,00	3,00



Table 4: Main Estimations

	Heckman		Country Differences: Adoption				Country Differences: Intensity			
	Intensity	Adoption	Reference: Switzerland		Reference: Germany		Reference: Switzerland		Reference: Germany	
			Germany	Austria	Switzerland	Austria	Germany	Austria	Switzerland	Austria
MAIN VARIABLES										
Taxes	-0.043	0.084*	0.206**	-0.155	-0.206**	-0.361**	0.101	0.211	-0.101	0.110
	(0.065)	(0.043)	(0.091)	(0.173)	(0.091)	(0.167)	(0.148)	(0.256)	(0.148)	(0.237)
Regulations	0.070	-0.010	-0.119	-0.217	0.119	-0.099	0.037	0.127	-0.037	0.090
	(0.065)	(0.046)	(0.095)	(0.189)	(0.095)	(0.188)	(0.143)	(0.241)	(0.143)	(0.230)
Voluntary agreements	-0.008	0.101**	-0.088	-0.478***	0.088	-0.389**	-0.049	-0.215	0.049	-0.167
	(0.065)	(0.047)	(0.095)	(0.185)	(0.095)	(0.186)	(0.141)	(0.223)	(0.141)	(0.218)
Public subsidies	0.182***	0.300***	-0.070	0.378**	0.070	0.448***	0.194+	0.400**	-0.194+	0.207
	(0.056)	(0.041)	(0.085)	(0.159)	(0.085)	(0.156)	(0.121)	(0.187)	(0.121)	(0.178)
Demand	-0.018	0.176***	-0.159*	-0.049	0.159*	0.110	0.056	-0.305	-0.056	-0.361+
	(0.069)	(0.046)	(0.094)	(0.158)	(0.094)	(0.157)	(0.148)	(0.235)	(0.148)	(0.227)
CONTROL ENERGY ENVIRONMENT										
High/volatile energy prices	0.222***	0.098**	-0.010	0.042	0.010	0.052	-0.063	-0.158	0.063	-0.095
	(0.063)	(0.042)	(0.085)	(0.173)	(0.085)	(0.170)	(0.138)	(0.252)	(0.138)	(0.242)
Energy shortage	-0.075	-0.098**	-0.018	-0.101	0.018	-0.083	0.013	0.044	-0.013	0.031
	(0.067)	(0.048)	(0.098)	(0.178)	(0.098)	(0.176)	(0.151)	(0.222)	(0.151)	(0.210)
CONTROL FIRM CHARACTERISTICS										
Number of employees	0.261***	0.078**	-0.065	-0.271**	0.065	-0.206*	0.105	0.237	-0.105	0.133
	(0.053)	(0.031)	(0.063)	(0.120)	(0.063)	(0.118)	(0.118)	(0.165)	(0.118)	(0.151)
Export	0.130	0.103*	-0.094	0.070	0.094	0.165	0.125	0.058	-0.125	-0.067
	(0.101)	(0.059)	(0.115)	(0.239)	(0.115)	(0.240)	(0.203)	(0.467)	(0.203)	(0.462)
Foreign owned	0.210*	-0.150*	0.019	-0.111	-0.019	-0.130	0.110	0.157	-0.110	0.047
	(0.121)	(0.077)	(0.182)	(0.224)	(0.182)	(0.257)	(0.274)	(0.330)	(0.274)	(0.344)
R&D propensity	-0.088	0.289***	-0.052	-0.097	0.052	-0.045	-0.136	0.267	0.136	0.403
	(0.097)	(0.059)	(0.114)	0.000	(0.114)	(0.203)	(0.193)	0.000	(0.193)	(0.316)

Share graduated employees	-0.001	0.000	-0.002	-0.001	0.002	0.002	0.005	0.005	-0.005	0.000
	(0.003)	(0.001)	(0.003)	(0.005)	(0.003)	(0.005)	(0.006)	(0.011)	(0.006)	(0.010)
Competition intensity	-0.008	0.008	-0.050	0.032	0.050	0.082	-0.061	0.148	0.061	0.209**
	(0.030)	(0.017)	(0.036)	(0.070)	(0.036)	(0.069)	(0.064)	(0.104)	(0.064)	(0.100)
Energy costs	0.186***	0.044**	0.012	0.057	-0.012	0.045	-0.053	0.048	0.053	0.101
	(0.035)	(0.021)	(0.044)	(0.044)	(0.044)	(0.085)	(0.083)	(0.083)	(0.083)	(0.090)
Gross tangible investments	0.449***	0.082***	0.020	0.176***	-0.020	0.155**	-0.092	-0.347**	0.092	-0.255**
	(0.040)	(0.018)	(0.038)	(0.064)	(0.038)	(0.063)	(0.091)	(0.141)	(0.091)	(0.125)
COUNTRY CONTROLS										
Swiss firm	-0.124	0.027			-0.836+				-0.615	
	(0.139)	(0.105)			(0.516)				(0.916)	
German firm	-0.529***	0.165*	0.836+				0.615			
	(0.140)	(0.092)	(0.516)				(0.916)			
Austrian firm				-1.410+		-2.246**		2.230*		1.615+
				(0.925)		(0.911)		(1.242)		(1.104)
EPIDEMIC ADOPTION		2.517***	-0.607	0.530	0.607	1.138				
		(0.353)	(0.723)	(0.783)	(0.723)	(0.813)				
Constant	0.435	-3.978***								
	(0.671)	(0.506)								
No. of observations			3439				1621			
Censored/uncensored	1818/1621									
R <sup>2</sup>							0.63			
Wald test of indep. eqns. (rho = 0): chi <sup>2</sup>	1.05									
	Wald chi2(48) = 2525.57***		Wald chi2(48) = 719.56***				F(78, 1542) = 39.84***			

Note: heteroscedasticity robust standard errors; all estimations include 2-digit sector controls; significance levels: (+ 0.15, \* 0.1, \*\* 0.05, \*\*\* 0.01).



Table 5: Margins

	Margins			
	Overall	Switzerland	Germany	Austria
Probabilities (constant)	0.49	0.40	0.55	0.56
<b>Taxes</b>				
not relevant (1)	0.47	0.40	0.52	0.63
relevant (2)	0.50	0.40	0.56	0.62
very relevant (3)	0.53	0.34	0.67	0.53
<b>Regulation</b>				
not relevant (1)	0.50	0.39	0.58	0.64
relevant (2)	0.46	0.37	0.54	0.52
very relevant (3)	0.53	0.49	0.56	0.59
<b>Voluntary agreements</b>				
not relevant (1)	0.48	0.37	0.55	0.66
relevant (2)	0.51	0.40	0.61	0.54
very relevant (3)	0.58	0.58	0.61	0.37
<b>Public subsidies</b>				
not relevant (1)	0.44	0.35	0.52	0.42
relevant (2)	0.55	0.44	0.60	0.75
very relevant (3)	0.68	0.66	0.72	0.89
<b>Demand</b>				
not relevant (1)	0.47	0.37	0.55	0.56
relevant (2)	0.56	0.44	0.64	0.67
very relevant (3)	0.58	0.60	0.57	0.83
<b>Fluctuating/high energy prices</b>				
not relevant (1)	0.47	0.37	0.54	0.55
relevant (2)	0.49	0.41	0.56	0.64
very relevant (3)	0.54	0.44	0.61	0.66
<b>(Feared) bottlenecks</b>				
not relevant (1)	0.50	0.40	0.58	0.66
relevant (2)	0.46	0.39	0.53	0.38
very relevant (3)	0.44	0.33	0.52	0.49

Note: Probabilities (constant) describe the probability to adopt an environmentally friendly, energy relevant technology. This means that the overall probability to adopt such technologies without taking into account policies or firm characteristics etc. is 50%.

Table 6: Adoption by type of technology and adoption of energy management systems

	Production	ICT	Transport	Buildings	Renewables	Management
Taxes	0.092* (0.047)	0.001 (0.045)	0.010 (0.049)	0.047 (0.044)	0.047 (0.058)	0.194*** (0.047)
Regulations	0.062 (0.047)	0.030 (0.046)	-0.080 (0.051)	-0.032 (0.045)	-0.078 (0.059)	0.045 (0.047)
Voluntary agreements	0.073 (0.047)	0.032 (0.045)	0.079 (0.052)	0.139*** (0.045)	0.019 (0.058)	0.277*** (0.048)
Public subsidies	0.189*** (0.041)	0.152*** (0.041)	0.040 (0.044)	0.257*** (0.040)	0.423*** (0.050)	0.073* (0.043)
Demand	0.153*** (0.048)	0.151*** (0.045)	0.266*** (0.048)	0.144*** (0.045)	0.144*** (0.055)	0.033 (0.047)
High/volatile energy prices	0.145*** (0.045)	0.068 (0.042)	0.129*** (0.048)	0.075* (0.042)	-0.019 (0.054)	0.030 (0.046)
Energy shortage	0.001 (0.051)	0.057 (0.047)	-0.005 (0.052)	-0.066 (0.049)	-0.063 (0.060)	-0.020 (0.048)
Number of employees	-0.036 (0.035)	0.075** (0.032)	0.167*** (0.035)	0.062** (0.031)	0.019 (0.039)	0.203*** (0.034)
Export	0.187*** (0.069)	0.152** (0.062)	-0.145** (0.073)	0.056 (0.061)	-0.009 (0.078)	0.178*** (0.066)
Foreign owned	-0.042 (0.080)	-0.023 (0.080)	-0.117 (0.091)	-0.200** (0.079)	-0.504*** (0.119)	0.300*** (0.081)
R&D propensity	0.334*** (0.063)	0.238*** (0.061)	0.185*** (0.069)	0.253*** (0.059)	0.168** (0.072)	0.202*** (0.062)
Share graduated employees	-0.001 (0.002)	0.005*** (0.001)	-0.001 (0.002)	-0.001 (0.001)	0.001 (0.002)	0.002 (0.002)
Competition intensity	-0.021 (0.021)	0.007 (0.018)	0.033 (0.020)	-0.020 (0.018)	-0.035 (0.024)	-0.022 (0.020)
Energy costs	0.116*** (0.026)	-0.008 (0.022)	-0.003 (0.023)	0.033 (0.021)	-0.010 (0.026)	0.070*** (0.023)
Gross tangible investments	0.098*** (0.022)	0.059*** (0.019)	0.051** (0.023)	0.103*** (0.018)	0.111*** (0.025)	0.040** (0.020)
Epidemic effect*	3.318*** (0.412)	3.433*** (0.479)	4.627*** (0.664)	2.443*** (0.350)	4.428*** (0.627)	2.659*** (0.464)
Swiss firm	-0.138* (0.073)	-0.056 (0.073)	-0.127* (0.072)	-0.206*** (0.071)	-0.067 (0.081)	-0.091 (0.077)
Austrian firm	-0.166 (0.102)	-0.128 (0.099)	-0.183 (0.120)	-0.155 (0.094)	-0.091 (0.127)	-0.033 (0.108)
Constant	-5.034*** (0.503)	-2.959*** (0.404)	-4.177*** (0.459)	-4.064*** (0.369)	-4.336*** (0.581)	-5.110*** (0.403)

Note: multivariate probit estimator with heteroscedasticity robust standard errors. \*) the epidemic effect refers to the respective technology or the management systems. Number of observation 3480, Wald chi2 (294) = 4444.34\*\*\*, Likelihood ratio test of  $\rho_{21} = \rho_{31} = \rho_{41} = \rho_{51} = \rho_{61} = \rho_{32} = \rho_{42} = \rho_{52} = \rho_{62} = \rho_{43} = \rho_{53} = \rho_{63} = \rho_{54} = \rho_{64} = \rho_{65} = 0$ :  $\chi^2(15) = 1493.89$ , Prob >  $\chi^2 = 0.0000$

## APPENDIX

Table A1: Determinants for propensity and intensity per country

	Propensity			Intensity		
	CH	D	AT	CH	D	AT
Taxes	-0.032 (0.072)	0.178*** (0.057)	-0.135 (0.172)	-0.110 (0.127)	-0.012 (0.080)	0.059 (0.270)
Regulations	0.070 (0.069)	-0.041 (0.066)	-0.165 (0.190)	0.044 (0.115)	0.091 (0.088)	0.156 (0.248)
Voluntary agreements	0.194*** (0.067)	0.100+ (0.069)	-0.360* (0.190)	0.041 (0.109)	-0.004 (0.094)	-0.180 (0.251)
Public subsidies	0.308*** (0.065)	0.234*** (0.056)	0.746*** (0.148)	-0.021 (0.097)	0.207*** (0.076)	0.532*** (0.188)
Demand	0.251*** (0.068)	0.102+ (0.067)	0.332** (0.161)	0.009 (0.120)	0.009 (0.095)	-0.213 (0.253)
High/volatile energy prices	0.084 (0.065)	0.082+ (0.056)	0.168 (0.167)	0.226** (0.113)	0.176** (0.086)	-0.098 (0.275)
Energy shortage	-0.069 (0.071)	-0.091 (0.068)	-0.379** (0.177)	-0.086 (0.118)	-0.061 (0.096)	-0.046 (0.225)
Number of employees	0.131*** (0.047)	0.073* (0.043)	-0.174 (0.135)	0.207* (0.106)	0.249*** (0.074)	0.419*** (0.148)
Export	0.141+ (0.087)	0.067 (0.087)	0.351 (0.272)	0.102 (0.161)	0.142 (0.149)	0.258 (0.519)
Foreign owned	-0.146+ (0.097)	-0.116 (0.158)	-0.387* (0.231)	0.250 (0.181)	0.352* (0.204)	0.319 (0.366)
R&D propensity	0.319*** (0.090)	0.315*** (0.083)	0.443** (0.225)	-0.079 (0.165)	-0.179 (0.136)	0.079 (0.402)
Share graduated empl.	0.003 (0.003)	-0.001 (0.002)	-0.005 (0.006)	-0.005 (0.005)	0.001 (0.003)	-0.014 (0.012)
Competition intensity	0.036 (0.028)	-0.021 (0.023)	0.034 (0.077)	-0.002 (0.050)	-0.049 (0.042)	0.108 (0.106)
Energy costs	0.032 (0.033)	0.037 (0.030)	0.111 (0.100)	0.180*** (0.069)	0.165*** (0.052)	0.264*** (0.090)
Gross tangible investments	0.053* (0.028)	0.070*** (0.026)	0.280*** (0.066)	0.545*** (0.082)	0.445*** (0.047)	0.164 (0.127)
Epidemic adoption	3.037+ (1.860)	-2.740 (3.783)	1.580 (2.576)			
Constant	-4.222*** (0.612)	-1.288 (1.435)	-5.464*** (1.036)	0.473 (0.922)	0.277 (0.625)	1.199 (1.465)
N	1584	1633	300	600	845	176
Wald chi2/R2	309.55***	268.50***	101.59***	0.58	0.63	0.65
Log Likelihood	-894.73	-969.87	-138.46	-1091.56	-1529.57	-296.71

