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Abstract

Environmental benefits only unfold if green (environmentally friendly) technologies are widely diffused and intensively deployed within a firm. We investigate how different types of policies - directly and in combination - affect the number of different green energy technologies adopted by a single firm (intra-firm diffusion). Using data from a dedicated survey on the diffusion of green energy technologies of 1200 Swiss firms and applying well-identified econometric models, we found that energy taxes are a very effective policy instrument for the intra-firm diffusion of green energy technologies. Even more important, however, are non-political measures that show the largest effect among all tested instruments. Additional analyses show that (a) time-consistency in policy making is more important for energy tax regimes than for regulations and (b) no evidence for complementarities between the policy types could be identified.

Keywords: Technology Adoption, Innovation, Policies, Intra-firm diffusion, Survey data
JEL classification: O31

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1 Introduction

Social/environmental benefits only unfold if green (environmentally friendly) technologies are intensively used and widely diffused. Quite often we observe that a technology which appears to be preferable to existing technologies will not be immediately chosen by firms. This is especially the case for “green technologies that are notoriously slower than traditional technologies at diffusing within and across firms” (Battisti 2008, p.29). One important reason for this is that the greatest benefits from the adoption of green technologies are likely to be public rather than private, and therefore firms’ willingness to pay for these technologies is low. As a consequence, policy intervention is required to stimulate the diffusion of green technologies. In-depth knowledge about the role of different policy instruments for the diffusion of green technologies is thus crucial.

The literature distinguishes between inter- and intra-firm diffusion. “Inter-firm” refers to the diffusion of a technology between firms and “intra-firm” refers to the diffusion of a technology or type of technology within a firm, measured as an intensity variable or – like it has been shown in Battisti et al. 2009 – coded as a binary variable pointing at the use of different technologies of the same type, which can be seen as a measure of the breadth of diffusion within a firm.

Although the literature is increasing there are still major gaps in the understanding of the relationship between green technology diffusion and the choice of policy instruments (Popp et al. 2010). First, although existing studies mainly focus on the *inter*-firm diffusion of green technologies, it could have been shown that *intra*-firm diffusion, i.e. the diffusion of a technology within a single firm, is crucial also for the understanding of the diffusion pattern of a technology in order to fully exploit the social benefits (Battisti and Stoneman 2005, Battisti et al., 2007). This is especially important for green technologies since considerable environmental benefits, e.g. drastic $C0_2$ reduction, only result if this type of technology is widely used within the firm. Hence, we measure intra-firm diffusion by the number of energy-saving technologies adopted by a firm. Actually, if a firm starts to “discover” the advantages of energy-saving technologies, for instance in one department, other units may follow and in the course of the time great parts of the value chain will be covered by different types of energy-saving technologies, which would clearly increase the benefits for the environment. Second, as existing studies mostly focus on the effect of a specific policy instrument for green technology diffusion, the relative impact of different policy types is rather unclear (exceptions are Popp 2006, Frondel et al. 2007, Veugelers 2012), although it better proxies economic reality. Moreover, we have to recognize that different (policy) measures cause different reactions from firms, which consequently might adopt several and different types of green energy technologies in order to adapt to the new policy environment. Empirical studies so far have insufficiently considered this fact.

In this paper, we analyze the effect of different (policy) instruments on green technology diffusion based on a unique survey about the adoption behavior of firms regarding green energy technologies. The data set includes information on the adoption decision of 2300 Swiss firms for 14 green energy technologies, which allows us to construct an overall measure for the *intra*-firm diffusion of green energy technologies and two specific measures for the *intra*-firm diffusion of energy-saving technologies and green energy/heat generating technologies. Moreover, the survey included a set of questions that directly asked the firms to assess the importance of different motives for the adoption of green energy technologies, which allows us to identify the relative effect of three categories of policies, i.e. energy taxes, regulation and subsidies, and several non-political motives. In contrast to previous studies, our policy measures are thus firm-specific, directly referring to the firms' adoption activities, and should consequently reflect the stringency of the different policy measures adequately, which is important in order to identify the relative firm-specific effect of the different (policy) instruments. Hence, even though a certain instrument may be of low relevance for the average firm, we do observe variation between single firms, and should thus be able to identify potential policy effects. Additionally, we can test the existence of complementarities between the policy types and the importance of time consistency of such policies. Another important advantage of the data is that it includes firm-level information capturing a broad set of potential drivers of green technology diffusion, which enables us to specify a widely accepted adoption model (Karshenas and

Stoneman 1995, Battisti et al. 2009) and thus to significantly reduce a potential omitted variable bias problem.

Based on our data set, we find that taxes and regulation are the most effective policy instruments for increasing the intra-firm diffusion of green energy technologies. Taking into account non-political motives, it was found 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. Moreover, the analyses provide some evidence that time consistency in policymaking is primarily relevant for taxes. The effect of a time-consistent policy approach in terms of taxes turns out to be significantly larger than the effect of a “current tax only” and “expected tax only” approach. We do not find evidence for complementarities among policies in terms of intra-firm adoption.

The paper is organized as follows. Section 2 provides an overview of relevant literature and states the hypotheses derived from the more theoretical literature. Section 3 describes the used data set and section 4 presents the econometric framework with which the hypotheses are tested. Section 5 shows the main results and provides some extensions to the standard model. Section 6 discusses the results and section 7 concludes the paper.

2 Empirical studies on the effects of policies on the adoption of “green” technologies

Technological advances are of little use until they widely diffuse across an economy. This is especially true for green technologies since significant positive effects for the environment can only be expected if, e.g. pollution reduction technologies are widely used.

However, quite frequently a technology that appears to be preferable due to its medium-term costs and due to its environmental performance will not be immediately chosen by customers, even though they are cost effective (Shama 1983) and their payback time is short. Anderson and Newell (2004), using US-data on energy audits, found that firms have only adopted 53% of recommended projects, although their payback time was on average just 1.29 years. Consequently, specific policy measures are necessary to trigger adoption. Which types of policies are effective? Theoretical papers assume that technology adoption leads to a decline in marginal abatement costs (discrete technology choice models), which indicates the financial incentives to adopt a new technology (Jung et al. 1996). Based on this view, it was basically found that market-based policy instruments (e.g. taxes, permits, subsidies) are more efficient than command-and-control instruments (e.g. regulation) in order to increase the adoption up to a socially optimal level where marginal abatement costs equals pollution price. There are only a few exceptions to these findings; see, e.g. Malueg (1989), who found that emission credit trading programs can decrease the incentive for firms to adopt new technologies. Milliman and Prince (1989) identified that auctioned emission permits, emission taxes, and subsidies provide the largest adoption incentives. Parry (1998) stated that emission taxes are more likely to support the introduction of major innovations since the greater an emission reducing technology diffuses, the more ambitious the emission reducing target has to be. Due to this, firms are likely not only to adopt a single technology but several in order to decrease emissions along their value chain. Also Requate and Unold (2003) show that taxes provide stronger incentives than permits (auctioned or freely allocated) if the regulator makes long-term commitments to policy levels. Because the marginal abatement costs would decrease under most of the applied policies, the regulator (policy maker) should adapt its policies according to the diffusion level. The private sector would oppose to a policy adaptation since it would imply, e.g. a decrease in subsidies and a decrease in the number of pollution permits. However, the diffusion level is negatively correlated with the optimal emission tax level. Consequently, the tax burden should decrease with diffusion (Milliman and Prince 1998).

From this perspective it is clear that market-based instruments are preferable to command-and-control policy instruments. Moreover there seems to be some consent among the tested market-based instruments that taxes are preferable to, e.g. permits. Based on the theoretical literature we can formulate the following hypotheses:

H1: Market-based policy instruments (e.g. taxes, subsidies) are more effective than command-and-control instruments (e.g. regulations).

H2: Environmental taxes are most effective among the market-based policy instruments in order to promote the adoption of green technologies.

There are many empirical investigations that focus on the effect of a single policy for the adoption decision in favor of green technologies (see Popp et al. (2010) for an overview). They confirm the benefits of market-based instruments (Jaffe et al. 2002). Keohane (2007) investigated the US Clean-Air-Act amendments and found that under the market-based tradable permit system, firms were more cost sensitive (they prefer cheaper scrubber to buying more expensive lower sulfur coal) than under the earlier emission rate standard. Popp (2006) investigated (Nitrogen oxid) pollution control technologies and found that regulation lead to end-of-pipe solutions (add-on technologies), while environmental audits (market-based) were strongly related to the adoption of cleaner production processes. On the contrary, regulation is related to the adoption of time-tested rather than innovative technologies (Purvis and Outlaw 1995) and to end-of-pipe solutions (Frondel et al. 2007).

Referring to regulation stringency of market-based instruments, Kerr and Newell (2003) investigated the adoption of lead-reducing refining technologies during the leaded gasoline phasedown in the US. Looking at 378 petroleum refineries spanning the period 1971 to 1995 and using a duration model, they found that higher prices (increased stringency) increased the adoption of lead reducing technologies.

Fewer studies simultaneously analyze the relative effect of different policy measures. Referring to adoption motives as a measure of policy affectedness, Veugelers (2012), based on Flemish CIS-data, 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 such technologies, i.e. the *inter*-firm diffusion. She finds that regulations/taxes show a larger effect than subsidies. Moreover, voluntary industry codes and agreements are important drivers for introducing green technologies. Why should firms adopt (costly) voluntary environmental programs? Howarth et al. (2000) investigated two voluntary programs, the Green Lights and the Energy Star program in the US and they thought that firm-internal issues can help find the reason for the effectiveness of such programs. The investigated programs caused relatively small investments, which are hard to monitor firm-internally. The saving opportunities are realized at the level of the firm at which the decision to invest in such programs is made.

To the best of our knowledge, there is no empirical study that investigates the relative inducement effect of several environmental policies for the *intra*-firm diffusion of green technologies. The lack of adequate data is surely one of the most important reasons for this.

3 Data description

The study at hand is based on firm-level data that were collected in the course of a postal survey on the "creation and adoption of energy related technologies" carried out in 2009. The questionnaire addresses a sample of 5809 firms (with more than five employees) covering the whole business sector (i.e. including services) of the Swiss economy, and is stratified by 29 industries and three industry-specific firm size classes (with full coverage of large companies). The survey yielded valid information for 2324 enterprises, implying a response rate of 40%, which is satisfactory given the very demanding questionnaire. Thanks to selective call reminders to firms that were underrepresented in a first round of data collection, the final structure of the responding firms in terms of size and industry affiliation is quite similar to that of the underlying sample.

As our policy measures are only available for firms that adopted at least one of the green energy technologies, this study focuses on the 1259 (about 54% of all valid responses) adopting firms. On average, the firms that reported the adoption of green energy technologies have 369 employees (median: 89 employees), whereupon 84% are SMEs with less than 250 employees. 55% of the firms belong to the manufacturing sector, 37% to the service sector and only 8% to the construction sector.

Besides questions on some basic firm characteristics (sales, exports, employment, investment and employees' vocational education), it included questions on energy related adoption activities as well as on motives and obstacles of such activities.[1] Descriptive statistics for all model variables based on the estimation sample are presented in Table A.1 in the appendix; the correlation matrix is shown in Table A.2.

The information on green adoption activities is based on questions that directly ask about the adoption of different green energy technologies comprising (i) a list of 13 *energy-saving* technology applications in (1) electromechanical and electronic applications[2], (2) motor vehicles and traffic engineering[3], (3) buildings[4]; and (ii) a list of 12 green (1) *energy*[5]- and (2) *heat*[6]*-generating* technologies.

On average, the 1,259 green adopters adopted 5.9 of the 25 green energy technologies included in the survey; 11.4% adopted more than 10 technologies. The number of adopted technologies depends on firm size. Large firms (more than 250 full-time employees) adopted an average of 7.6 technologies, medium sized firms (50-250 full-time employees) adopted 6.1 technologies and small firms (fewer than 50 full-time employees) adopted 5.2 technologies. The adoption behavior differs only marginally across sectors. While manufacturing firms adopted an average of 6.1 technologies, firms in the construction and service sector adopted an average of 5.8 and 5.7 technologies, respectively. The adoption of energy-saving technologies is much more frequent than the adoption of energy-or heat-generating technologies. 97.4% of the green adopters adopted at least one of the

[1] The questionnaire is available in German, French and Italian on www.kof.ethz.ch/en/surveys/structural-surveys/other-surveys.
[2] These include applications in (a) electrical machines and drive systems, (b) information and communication technologies, (c) consumer electronics, (d) components of process engineering (e.g., compressors; pumps; heat exchangers), and (e) process engineering.
[3] These include applications in (a) engines of motor vehicles, (b) motor vehicle bodies (e.g., through the decrease in weight; the improvement of aerodynamics), and (c) traffic management system.
[4] These include applications in (a) temperature isolation, (b) lighting (incl. respective control systems), (c) heating (incl. respective control systems), (d) cooling systems, and (e) air ventilation and air conditioning.
[5] These include (a) photovoltaics, (b) electricity based on biomass, (c) wind power, (d) combined heat and power generation based on biomass, (e) combined heat and power generation based on oil/gas/carbon, and (f) hydro-electric power station.
[6] These include (a) solar technology, (b) heat generation based on biomass, (c) geothermal energy, (d) heat pumps, (e) heat recuperation systems, and (f) heat from a district heating network.

energy-saving technologies; whereby they adopted an average of 5.0 of the 13 technologies. 51.3% of the firms adopted energy- and heat-generating technologies; whereby on average they adopted 2.1 out of the 12 technologies.

The identification of the relative effect of different government policy types at firm level is hardly possible based on publicly available data. It requires survey data for at least three reasons. 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, besides the identification of relevant policies, also the stringency of single policies (e.g. the amount of received subsidies) has to be identified. The stringency, i.e. how strong a firm is affected, varies across firms, which makes it difficult to identify it. Third, as our focus is on the adoption of green technologies, we are interested in policies that are related to such adoption activities. A firm, however, may also be confronted with policies that affect other firm activities, e.g. subsidies for the *generation* of green technologies. Hence, the policy measures not only have to be firm specific, but also directed to the *adoption* of technologies.

To overcome these problems, we included a set of questions in our survey that directly asked the firms to assess the importance of different policy types for the adoption of green energy technologies (for a similar procedure see, e.g. Johnstone et al. 2012, Lanoie et al. 2011, Veugelers 2012). More precisely, the information on government policies comes from a set of questions dealing with the motives for adopting green energy technologies, the importance of which has been assessed by the firms on a five-point Likert scale. A first set of questions refers to three categories of policies, i.e. energy taxes, regulation and subsidies. Furthermore, for taxes and regulations we can distinguish between the relevance of current and expected future policies. Additionally, information on the impact of the energy price and four non-political motives is available. Non-political motives include (a) current or expected demand for green products, (b) compliance to agreements with government agencies, (c) protection of environment, and (d) uncertainty as to future energy bottle-necks.

The policy measures should be interpreted against the "restrained" policy framework, in Switzerland. It consists of a CO2-tax (levy; since 2008)) that was part of the first commitment period of the Kyoto protocol and the Swiss emission trading system (for heavy polluters). Moreover there are regulations concerning labelling (information), promotion and instalment of renewable energy plants, e.g. photovoltaic plants, technical trade restrictions, and an education and communication program that should promote voluntary climate protection measures.[7] Subsidies mainly refer to the "building program", which supports investments to increase the energy efficiency in buildings (a more detailed discussion on how the Swiss policy framework may affect the estimation results is presented in Section 6).[8] Even though we do not observe intensive use of policy instruments in Switzerland, our firm-level measures are sensitive enough to capture variance between firms. Table A.1 shows that for each policy instrument between 20-30% of the firms were heavily affected. Moreover, as our measures are at the firm level, we can use within-industry variation in order to identify the policy effects.An obvious drawback of these policy measures is that the information is only available for firms with adopting activities. Hence, by using these policy measures, we have to restrict our analysis to the *intra*-firm diffusion of green technologies and cannot identify potential differences between *intra*-firm and *inter*-firm diffusion (potential selection problems are discussed in Section 4). Moreover, the policy measures may share a common unmeasured cause with intra-firm diffusion of green technologies, i.e. firms with a larger intra-firm diffusion level may systematically feel more policy affected than other firms. Hence, the intra-firm diffusion level may affect the policy variables and not vice versa. As a consequence, we have to be careful when interpreting our results. As the different policy variables should be similarly affected by this problem, we do not interpret the effects of the different policies individually, but focus on the interpretation of the different policy effects relative to each other.

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[7] There is also an emission regulation for passenger cars–similar to the EU-regulations–which has been effective since 2012. This means after the survey was conducted. Hence, this regulation is not relevant for the study at hand.

[8] There are also subsidies 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.

4 Econometric framework

The firms' number of adopted green energy technologies is used as a measure for adoption intensity in our baseline specification, which is a count variable ranging from 1 to 25. Obviously, this variable is restricted by an upper bound, making Poisson or Negative Binomial distributions not applicable. Hence, we transformed our dependent variable into a fraction variable by dividing the variable by the upper bound, which then allows us to estimate a fractional logit regression (see Wooldridge 2002).

To capture alternative effects that are expected to drive a firm's adoption behavior, we include the policy variables in a standard adoption model. Hence, we will estimate an adoption model for green energy technologies 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, and by Arvanitis and Ley (2013) in terms of energy-saving technologies. According to this literature, the adoption of a new technology in time *t* by firm *i* in industry *j*, *Di(t)*, are determined by five categories of variables: 1) a vector of characteristics of a firm *Ri(t)* and its environment *Rj(t)* reflecting rank effects referring to, e.g. energy intensity, competition, and obstacles, 2) the extent of industry usage of new technology *SOj(t)* to capture inter-firm stock and order effects (i.e., market-intermediated externalities), 3) epidemic effects (i.e. learning and network non-market intermediated externalities) reflecting the experience gained from observing other firms *Ej(t)* (often measured by the extent of technology diffusion among similar firms in time t),[9] 4) the expected adoption cost of a unit technology *Pi(t)* that is constituted by two parts: one common to all firms, e.g. the price of a new, energy technology, and a second one reflecting firm-specific adjustment and installation costs. 5) In accordance with 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

[9] In fact, the standard model would also include a control for the firm's own experience with the new technology *Ei(t)*, often proxied by the time since the firm's first adoption. However, as we do not have such information in our survey, this type of experience has to be ignored.

increases in energy prices and/or taxes (see, e.g. Linn 2008 and Jacobs et al. 2009) and (b) through public regulation and/or public incentives for the use of green energy technologies (see, e.g. Popp et al. 2010). We consider a vector *IAi(t)* of variables that capture the influence of such factors (inducement effects). We therefore arrive at the following equation, which we use for estimating the adoption models:

$$Di(t) = f\{Ri(t), Rj(t), SOj(t), Ej(t), Pi(t), IAi(t)\} \quad (1)$$

For the empirical implementation of the model, we follow Arvanitis and Ley (2013). Firm-specific *rank effects* are measured by (a) the firm's number of employees, (b) investment intensity, (c) the qualification level of the employees, (d) firm's R&D activities, (e) export activities, and (f) foreign ownership. Rank effects as to the firms' market environments are proxied by (a) the expected demand development, (b) intensity of price competition, (c) intensity of non-price competition, and (d) industry affiliation. 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.[10] *Adoption costs* are measured by the intensity of (a) information and knowledge barriers, (b) adjustment barriers, (c) financing barriers, and (d) organizational and managerial barriers. Finally, in order to capture *inducement effects* we control for (a) the firm's sales share of energy costs, (b) the firm's environmental awareness proxied by a variable measuring whether environmental criteria are taken into consideration for purchases of intermediate inputs, and most importantly for this paper (c), the firm's political environment, which is measured by motive variables referring to regulation, subsidies and energy taxes. Furthermore, to

[10] In our analysis of the intensity of technology adoption by technology type, we additionally control for inter-firm epidemic effects that are measured by the share of firms within a 2-digit industry adopting at least one of the technology applications listed under the respective type. Such a control does not make sense in the baseline model as per definition only adopting firms are included.

distinguish the policy effect from alternative drivers of green technology adoption, we control for (d) the effect of energy prices,[11] and (e) general non-political motives.

Because only firms that have adopted at least one of such technologies can assess the importance of the different policies for the adoption, the motive variables are available for adopting firms only. As a consequence, we have to focus on our regressions on adopting firms. A Heckman (1979) model is estimated to test for selection bias, whereby the following adjustments were made compared with our baseline specification. First, as our dependent variable measuring the intra-firm diffusion of green energy technologies has an upper bound, the error term of the intensity equation per definition is not normally distributed, which is one of the main assumption of the Heckman model. Consequently, we transform this variable to a binary variable (value 1: adoption of many technologies (=75% percentiles); value 0: adoption of few 8 technologies)[12]. Second, as the motive variables are only available for adopting firms, we had to drop the motive variables from the intensity equation to ensure that the same covariates appear in the selection equation and the intensity equation, which is a precondition of the Heckman model to obtain formal identification. Third, the variable *adjustment barriers* is used as exclusion restriction. Hence, we dropped this variable from the intensity equation. The variable *adjustment barriers* measures the lack of compatibility of green technologies with the firm's current product program and production technology (see Table 1 for exact definition). As the adjustment costs are expected to mainly reflect fixed costs, *adjustment barriers* should affect a firm's propensity of green technology adoption, but not the intensity of adoption. This is confirmed empirically, since *adjustment barriers* significantly affect adoption propensity but not intensity (see columns 1 and 3 of Table A.3).

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[11] The fluctuation of energy prices has a price component and a tax component. As we control in our model for tax effects, the remaining variation in the energy prices in our model is mainly due to fluctuations in the price components, which is not directly policy driven.

[12] Similar to Battisti et al. 2009 or Battisti et al. 2007 in terms of ICT (Information and Communication Technologies) we coded the intra firm level in form of a binary variable (enhanced user/adopter). Many means more than 8 technologies and few means less or equal than 8 technologies; we made robustness tests with different thresholds.

The estimation results of the Heckman model are presented in Table A.3. As the inverse Mills ratio does not turn out to be statistically significant, there is no evidence for a selection bias. In what follows, we thus directly interpret the results of the *intra*-diffusion model.

A potential problem is the possible endogeneity of some of the right-hand variables that would imply inconsistent estimates. As our study is based on data for a single cross-section, we cannot directly handle this problem. However, since a broad set of observables that generally affect the firms' adoption activities is included in the estimation equations besides the policy variables, our 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.[13] We thus expect that the policy variables affect the firms' adoption intensity directly and endogeneity is not a main concern.

5 Estimation results

5.1 Main results

The main results are presented in Table 2. With respect to the policy variables, only energy taxes show a significant positive effect when controlled for all other motives (see estimation (1) in Table 2). The effect of regulation is not statistically significant in the full model, but gets significantly positive (compliance with state requirements) if we drop other policy variables (see estimation (4) in Table 2). Subsidies show a negative relationship with adoption intensity which disappears if we drop the other policy variables from the model (see estimation (3) Table 2). Hence, the negative effect results from strong correlation with other policy variables. This indicates that a positive adoption effect of subsidies is covered by other policy variables. However, we identify a positive but not statistically significant effect of subsidies when we control for complementarities between the different policy types (see Table 4).

[13] Even more so as we are primarily interested in the effects of the different policy types relative to each other.

Besides the policy variables, non-political motives turn out to have a significant positive effect. The effect of energy prices is not statistically significant, which is not very surprising as the tax variable captures the tax component of the energy-price fluctuations and the model also includes a control for energy costs.

One advantage of our setting is that we can directly compare the size of the policy effects and the results allow for a type of policy ranking. Pairwise Wald-tests based on the results of the full model presented in estimation (1) in Table 2 indicate that the effect of energy taxes and regulations is significantly larger than the effect of subsidies (and energy prices). The coefficients of regulation and taxes, however, statistically are not significantly different from one other. Hence, the effect of regulation, which is our proxy for command-and-control measures, seems to be more effective than subsidies in stimulating the intra-firm diffusion of green energy technologies. Furthermore, the effect of energy taxes is not significantly larger than the effect of regulation. Consequently, we have to reject H1 that market-based instruments are preferable to command-and-control measures. However, we cannot reject H2 (environmental taxes are most effective among the market-based policy instruments) since taxes exert the greatest coefficient among the two market-based instruments.

When considering all motives, the results indicate that non-political motives are the most influential driver for the intra-firm diffusion of energy related technologies. The effect of non-political motives is significantly larger than the effects of all other motive variables. This overall picture holds even if we run separate estimations for single policy types.

The results for non-political motives and subsidies so far were based on variables that are composed of different sub-categories. To test whether the results differ between these sub-categories, Tables A.4 and A.5 show the results when the variables referring to the different sub-categories of non-political motives and subsidies, respectively, are included.[14]

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[14] Similar to the policy variables in the baseline specification, the 5-level ordinate sub-category variables are transformed to binary variables for these regressions.

The overall results for non-political motives are mainly driven by “voluntary agreements”. Although every single factor that is inserted in the estimation shows a significant and positive effect, the effect of “voluntary agreements” is significantly larger than the other effects when simultaneously estimated. Concerning the overall results for subsidies, we can neither simultaneously nor alternatively estimated, observe robust significant effects for “CO2 reduction subsidies” and “Energy efficient subsidies”.

As expected, the coefficients for firm size, investment intensity, R&D activities (rank effects) are significant and positively related to the adoption intensity. Foreign owned firms show a significantly lower adoption intensity compared to domestic firms.

Energy costs are positive and significantly related to the adoption intensity. Furthermore, firms with greater environmental awareness adopted green energy technologies more frequently. Referring to the epidemic effect[15], we see a positive and significant coefficient indicating that the incentives for adoption increase with the number of firms in an industry that have already adopted such technologies. Higher non-price competition tends to be also positive and significantly associated with the adoption intensity. This means that firms in markets with competition that is characterized by product differentiation, great product obsolesce, and technical advancements have adopted more energy-efficient technologies on average, compared to a competitive environment that is less characterized by non-price competitive factors. The unexpected sign for the adoption obstacle “information barriers” is a sign that only intensively adopting firms become aware of the technological complexity and the resulting lack of further information about technological options.

5.2 Extensions

Relevance of the policies’ time consistency

[15] Given the cross sectional character of the paper we cannot distinguish between stock and order effects. Hence our coefficient of our measure for epidemic affects mirrors the net value of stock and order effects.

For taxes and regulations, the data includes separate information on the relative importance of current and expected policies, respectively, which allows us to test the relevance of the policies' time consistency. For both policy types we do so by grouping the adopting firms into four categories: firms that are affected only by current policy, only by expected policy, by both current and expected policy and firms that are not affected by the policy type at all.[16] The results in Table 3 show that time consistency in terms of energy taxes as well as time consistence in terms of regulation is positive and significantly associated with the adoption intensity. However, the significant positive sign for regulation consistency only shows up if we do not control for other policies. This clearly indicates that the regulation effect catches positive effects from other policies. When comparing the different effects with each other, the results indicate that time consistency is primarily relevant for taxes. The effect of time-consistent tax turns out to be significantly larger than the effect of "current tax only" and "expected tax only" (based on pairwise Wald tests). The effect of time-consistent regulation, however, is not significantly larger than expected regulation only and current regulation only (based on pairwise Wald tests).

Testing for complementarities between the policy types

To identify potential complementarities between the policy types, we analyze the effect of combinations of the three policy variables within a firm. In Table 4 we estimate once more the baseline adoption model inserting now instead of the original (binary) policy variables all possible combinations of these variables (reference group: firms that are not affected by policy at all), including the "pure" cases with only one policy (combinations: t1_s0_r0 (only energy tax); t0_s1_r0 (only subsidies); t0_s0_r1 (only regulation) in Table 4). We find statistically significant positive effects for the exclusive use of taxes and regulations on the *intra*-firm diffusion of green energy

[16] The tax and regulation variables are measured on a 5-point Likert scale. To define these categories, the variables first had to be transformed into binary variables (value 1: levels 4 and 5; value 0: levels 1, 2 and 3). For both types of policies the categories 'only expected policy' are firms with value 0 for the current policy variable and value 1 for the expected policy variable; 'only current policy' are firms with value 0 for the expected policy variable and value 1 for the current policy variable; 'time-consistent policy' are firms with value 1 for both current and expected policy variables (reference group: neither current nor expected policy).

technologies. The effect for the exclusive use of subsidies turns out to be positive but not statistically significant. Furthermore, we find that a combination of taxes and regulations also have a significant positive effect on the *intra*-firm diffusion. However, as statistically speaking the effects of *all* possible combinations of policies turn out to be insignificantly larger than the effects of single policy use (based on pairwise Wald tests), we do not find evidence for complementarities.

Testing for varying effects for different technology categories

To test whether the policy effects differ between different categories of green energy technologies, we estimate the adoption model in Table 5 for energy-saving technologies and green energy/heat generating technologies, respectively. The results for the adoption of energy-saving technologies are very similar to our previous findings referring to overall-adoption. Again, the adoption seems to be driven by non-political motives, energy taxes and regulation, whereby not even the relative size of the effects changes. However, we observe a different picture for the adoption of green energy/heat generating technologies that are still affected by non-political motives but not by political instruments.

6 Discussion of the results

Effective policy measures should not only increase the adoption propensity of green technologies, but also their *intra*-firm diffusion, i.e. the intensity of use. In this paper, we measured intra-firm diffusion by the number of green technologies that has been adopted by a firm. Existing studies in this research field look at the *inter*-firm diffusion of such technologies. Kerr and Newell (2003) are an exemption. They found that increased policy stringency also increased the intensity of (lead reducing) technological adoption.

To better understand the estimation results, we must first present some information about the political framework in Switzerland. Switzerland is a very liberal country with only few regulations and financial support for the innovation activities (including adoption) of Swiss firms, including the adoption of green technologies. The main policy instruments in this field in Switzerland which were in place before the survey was conducted refer to measures that reduce the CO_2 level according to the Kyoto protocol. The Swiss government introduced the ETS (Emission trading system) in 2008, launched a CO_2 tax, installed a building program to improve thermal insulation, encouraged investments in renewable energies, and supported the improvement of building technology. Against this rather poor policy background it is not very surprising that we do not find any significant effect of subsidies for the *intra*-firm adoption. From the literature on *inter*-firm diffusion it becomes clear that subsidies are an effective instrument since they address the up-front costs of installing green technologies (Jaffe and Stavins 1995). However, a subsidy usually addresses the adoption of one specific type of technology (e.g. insulation techniques) and it does not encourage firms to adopt many different technologies (e.g. insulation techniques and energy saving ICT). Hence, given that subsidies in Switzerland and their orientation towards a specific type of technology are practically inexistent, the insignificant effect of subsidies for intra-firm adoption of green energy technologies is understandable.

Taxes are one of the most effective policy measures for the intra-firm adoption of technologies. They encourage firms to adopt green technologies in different areas and they increase the positive environmental impact of such a measure. Taxes also create some confidence that government policies towards a more environmentally friendly economy are sustainable. This is also suggested by our measures for time-consistency in tax policies: here we see a significant and positive effect.

Similarly, we see that non-political motives (voluntary measures) show a strong positive effect on intra-firm adoption. That is somehow curious since such actions may cause additional costs for firms. However, assuming rational firm behavior, such voluntary measures are adopted for two reasons. First, firms want to avoid future governmental interventions which might distort competition. Consequently, they prefer to send a signal that the industry can take proper steps to decrease the negative environmental impact. Hence, even non-political motives may indirectly be driven by the political framework in Switzerland. Second, they can select measures, e.g. labels that are simple and inexpensive and are beneficial for committed firms since it increases the readiness to pay for such products and services given the receptivity for environmental issues of the population.

Given the controls for other policy measures, regulation does not show any effect on intra-firm adoption, but considering the time-consistency of regulation, we see a significant and positive relationship. However, this effect is driven by certain specific categories of technology adoption that are usually confronted with more regulation, i.e. we identified that the observed regulation effect is primarily driven by adoption decisions concerning energy-saving technology applications in electromechanical and electronic applications, and within this category for applications in (a) electrical machines and driving systems and (b) components of process engineering (e.g. compressors, pumps, heat exchangers).[17]

Another interesting result is that time-consistency turns out to be more relevant for taxes than for regulation. As firms have to react to current regulation irrespective of potential (unknown) future regulations, it is not that surprising to find no significantly larger effect of time-consistent regulations than of current regulations only. In contrast, a combination of current and future taxes significantly increases the incentives for current adoption compared to only current taxes. The option to decrease the current and future tax burden by adopting green energy technologies is clearly more attractive than to timely react to uncertain future regulation with unclear benefits.

As mentioned in the beginning, existing studies mostly focus on the effect of a specific policy instrument for green technology diffusion (inter-firm). Hence, it is hardly possible to compare our findings for the relative impact of different policy types for intra-firm diffusion with previous studies. Most related to our investigation is the study by Veugelers (2012) that is also based on survey data and covers the whole business sector. Although the main focus of this study is on clean innovating in general, it presents some evidence on the link between two policy variables (i.e. taxes/regulation and subsidies) and the likelihood that firms introduce innovations to reduce the energy use within the firm, which can be interpreted as a measure for the inter-firm diffusion of energy-saving technologies.

[17] These results are available from the authors on request.

To compare our results with the findings of Veugelers (2013), which are based on Flemish data, allows us to gain some evidence on whether inter-firm diffusion and intra-firm diffusion of green energy technologies are driven by similar policies (motivations). Veugelers (2012) found that voluntary agreements have a larger direct effect on the inter-firm diffusion of energy-saving technologies compared to regulation/taxes and subsidies. These results are in line with our finding for the intra-firm diffusion. Furthermore, time-consistency seems to be of low importance for adoption. This result may be related to the fact that Veugelers (2012) does not distinguish between taxes and regulations, which is likely to be important since time-consistency seems to be more relevant for taxes than for regulations, at least for intra-firm diffusion in Switzerland. Veugelers (2012) also found some evidence for complementarities between the two policy types. The combined effect of taxes/regulations and subsidies seems to be significantly larger than the direct effects of the two policy variables, respectively. This is not in line with our finding for the intra-firm diffusion, where no such complementarities can be detected. Given that subsidies do not show a direct effect in our model, it is not surprising that we do not detect complementarities between subsidies and regulation. The drivers of the different findings in terms of subsidies, however, are not a priori clear. As discussed above, a possible explanation for this difference is that subsidies seem to be more efficient in stimulating the inter-firm diffusion than the intra-firm diffusion of these technologies. A further explanation may be that the difference is due to a larger relevance of subsidies in Flanders compared to Switzerland.

7 Conclusions

The paper investigates the inducement effects of several policies and non-policy motives on the adoption intensity (intra-firm adoption) of green (environmentally friendly) energy technologies. Hence, we basically assess the environmental impact of policies since the more environmentally friendly the technologies adopted by a firm are, the lower the environmental burden of the production process. The paper offers several advantages over existing investigations. First, we can assign the importance of every single policy measure to one adopting firm. Second, we can simultaneously assess the inducement effect of several measures, i.e. energy taxes, subsidies, regulation, energy price, and non-political motives. Thirdly, we do not look at the adoption propensity (inter-firm diffusion), but instead investigate the adoption intensity (intra-firm diffusion) based on a comprehensive catalogue of green energy technologies. Fourth, we have a rich vector of firm-level information that accounts for the "rank" effects and "epidemic" effects of traditional technology diffusion models (Karshenas and Stoneman 1995, Battisti et al. 2007) and we reduce the risk of endogeneity due to an omitted variable bias.

Using data from a detailed survey among a representative sample of 5809 firms (response rate 40%) on the diffusion of green energy technologies in Switzerland, and applying well identified econometric models including "Heckman" estimations in order to address a possible selection problem, we found that "voluntary agreements" (non-political motives) are the most effective motive for inducing the intra-firm adoption of more green energy technologies followed by energy taxes and regulation. However, we have to keep in mind that the importance of non-political motives is also driven by policies. This means that "voluntary agreements" require the availability of green energy technologies and the availability of such technologies is more likely if adequate policies are in place. Moreover, it was found that time-consistency concerning governmental tax regimes is important since it very likely increases the confidence of firms that markets for green produced products or services will evolve due to rising awareness of customers or due to internalized production externalities. Markets are usually characterized by many different operating policies and their complementarity might bring additional adoption impulses. However, the study at hand does not detect complementarities among different policy types. This might be due to the overall low policy affinity of the Swiss Government, also in terms of green energy technologies. In sum, we see that a consistent policy approach in terms of energy taxes as well as non-political arrangements are very important for boosting the adoption of green technologies, which in turn would reduce the environmental burden of industry production.

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Table 1: Variable definition and measurement

Dependent variables	
Energy-saving adoption fraction	Fraction of adopted energy-saving technologies (fraction of the 13 energy-saving technologies included in the survey that were effectively adopted by the firm)
Energy/heat generating adoption fraction	Fraction of adopted green energy/heat generating technologies (fraction of the 12 energy/heat generating technologies included in the survey that were effectively adopted by the firm)
Total adoption fraction	Fraction of adopted green energy technologies (fraction of the 13 energy-saving and the 12 green energy/heat generating technologies included in the survey that were effectively adopted by the firm)
Independent variables	
Rank effects	
Firm size	Natural logarithm of the number of employees (in full-time equivalents) by the end of the year 2008
Investment intensity	Natural logarithm of gross investment expenditure per employee in the year 2008
Tertiary share	Employment share of employees with tertiary-level education by the end of the year 2008
R&D activities	R&D activities yes/no in the period 2006-2008
Export activities	Export activities yes/no in the year 2008
Foreign owned	Foreign-owned firm yes/no
Demand expectations	Expected change of demand for a firm’ s main product for the period 2009-2011 (5-level ordinate variable (level 1: 'strong decrease'; level 5: 'strong increase'))
Price competition	Intensity of price competition (5-level ordinate variable (level 1: 'very weak': level 5: 'very strong'))
Non-price competition	Intensity of non-price competition (5-level ordinate variable (level 1: 'very weak': level 5: 'very strong'))
Industry dummies	Controls for industry affiliation (IND1: NACE 22, 335, 36, 37; IND2: NACE 21, 23, 24, 25, 26, 27, 28, 40, 41; IND3: NACE 29, 31, 30, 31, 32, 331-334, 34, 35 ; IND4: NACE 45; IND5: 50, 51, 52; IND6: 55, 60-63, 70, 71; IND7: 64, 65-67, 72, 73, 74, 93; reference: NACE 15-20)
Adoption costs	
Information barriers; Organizational barriers; Financing barriers; Adjustment barriers	Barriers of adoption: - Information and knowledge barriers: Anticipated falling price trend makes adoption currently unattractive; technology not mature enough; information problems/costs; performance of technology still uncertain - Organizational and managerial barriers: Inadequate know-how; lack of specialized personnel; management thoroughly absorbed by other tasks; uncertainty with respect to public regulation - Financing barriers: technology too expensive; too large investment volume; too long payback period; lack of liquidity - Adjustment barriers: Lack of compatibility with current product program; lack of compatibility with current production technology (Factor values; Transformation of 14 5-level ordinate variables (level 1: 'very low importance': level 5: 'very high importance') into 4 factor variables based on principle components factor analysis; more detailed information on the factor scores is available from the authors on request)
Epidemic effects/Stock and order effects	
Industry's total adoption intensity; Industry's efficiency adoption intensity; Industry's generation adoption intensity	Average number of adopted technology applications listed under (a) total green energy related technologies, (b) green energy efficiency technologies, or (c) green energy/heat generating technologies, respectively, by *2-digit industry*
Industry's efficiency adoption propensity; Industry's generation adoption propensity	Share of firms adopting at least one technology applications listed under (a) green energy efficiency technologies, or (b) green energy/heat generating technologies, respectively, by *2-digit industry*
Inducement effects	
Energy costs	Natural logarithm of the sales share of energy costs in the year 2008
Environmental awareness	Environmental criteria are taken into consideration for purchases of intermediate inputs (5-level ordinate (level 1: 'very low importance'; level 5: 'very high importance'))

Energy tax	Importance of energy taxes for the adoption of the green energy technologies (transformation of two 5-level ordinary variables referring to the importance of (a) current and (b) expected taxes (level 1: 'very low importance'; level 5: 'very high importance') to a binary variable (value 1: mean≥4; value 0: mean<4))
Subsidies	Importance of public subsidies for the adoption of green technologies (transformation of two 5-level ordinal variables referring to the importance of public incentives for (a) energy efficiency and (b) CO_2 reduction to a binary variable (value 1: mean≥4; value 0: mean<4))
Regulation	Importance of public regulations for the adoption of green technologies (transformation of two 5-level ordinal variables referring to the importance of (a) current and (b) expected public regulations to a binary variable (value 1: mean≥4; value 0: mean<4))
Energy price	Importance of high/increasing energy prices for the adoption of green technologies (transformation of a 5-level ordinal variable to a binary variable (value 1: levels 4 and 5; value 0: levels 1, 2 and 3))
Non-political motives	Importance of non-political motives for the adoption of green technologies (transformation of four 5-level ordinal variables referring to (a) current or expected demand for environment-friendly products, (b) compliance to agreements with government agencies, (c) protection of environment, and (d) uncertainty as to future energy bottle-necks to a binary variable (value 1: mean≥4; value 0: mean<4))

Table 2: Main model based on fractional logit regressions

Dependent variable	Total adoption fraction					
	(1)	(2)	(3)	(4)	(5)	(6)
Firm size	0.158***	0.162***	0.162***	0.157***	0.162***	0.160***
	(0.016)	(0.016)	(0.016)	(0.017)	(0.016)	(0.016)
Investment intensity	0.064***	0.062***	0.062***	0.062***	0.062***	0.065***
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
Tertiary share	-0.001	-0.001	-0.001	-0.002	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
R&D activities	0.151***	0.152***	0.154***	0.155***	0.155***	0.148***
	(0.057)	(0.057)	(0.057)	(0.057)	(0.057)	(0.057)
Export activities	-0.029	-0.028	-0.031	-0.033	-0.031	-0.028
	(0.060)	(0.060)	(0.060)	(0.060)	(0.060)	(0.060)
Foreign owned	-0.200***	-0.206***	-0.201***	-0.195***	-0.202***	-0.201***
	(0.066)	(0.066)	(0.066)	(0.066)	(0.066)	(0.066)
Demand expectations	0.049*	0.050*	0.046	0.047*	0.046	0.047*
	(0.028)	(0.028)	(0.029)	(0.028)	(0.029)	(0.028)
Price competition	0.015	0.018	0.020	0.021	0.021	0.016
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
Non-price competition	0.041	0.047*	0.049*	0.048*	0.049*	0.046*
	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)
Information barriers	0.055**	0.061**	0.071***	0.064***	0.072***	0.054**
	(0.025)	(0.025)	(0.025)	(0.024)	(0.025)	(0.024)
Organizational barriers	-0.034	-0.031	-0.024	-0.027	-0.024	-0.033
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)
Financing barriers	-0.012	-0.017	-0.010	-0.013	-0.009	-0.012
	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)
Adjustment barriers	-0.012	-0.013	-0.009	-0.009	-0.009	-0.005
	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)
Energy costs	0.071***	0.074***	0.074***	0.073***	0.073***	0.072***
	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
Environmental awareness	0.126***	0.147***	0.152***	0.149***	0.151***	0.128***
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
Industry's total adoption intensity	0.068*	0.076**	0.075**	0.071**	0.074**	0.070**
	(0.035)	(0.036)	(0.036)	(0.036)	(0.036)	(0.035)
Energy tax	0.102*	0.116**				
	(0.055)	(0.051)				
Subsidies	-0.120*		-0.011			
	(0.063)		(0.058)			
Regulation	0.092			0.126**		
	(0.061)			(0.057)		
Energy price	-0.062				-0.015	
	(0.053)				(0.051)	
Non-political motives	0.263***					0.270***
	(0.066)					(0.063)
Constant	-3.716***	-3.866***	-3.838***	-3.807***	-3.826***	-3.781***
	(0.290)	(0.288)	(0.290)	(0.290)	(0.292)	(0.288)
Industry dummies	yes	yes	yes	yes	yes	yes
N	1234	1234	1234	1234	1234	1234
Pearson chi-square statistics	718.98	732.49	738.19	736.43	738.58	728.24
Root mse	0.60	0.61	0.61	0.61	0.61	0.60

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

Table 3: Relevance of time consistency of the policies; fractional logit regressions

Dependent variable	Total adoption fraction			
	(1)	(2)	(3)	(4)
Firm size	0.158***	0.162***	0.156***	0.155***
	(0.016)	(0.016)	(0.016)	(0.017)
Investment intensity	0.064***	0.062***	0.064***	0.061***
	(0.015)	(0.015)	(0.015)	(0.015)
Tertiary share	-0.001	-0.001	-0.001	-0.002
	(0.001)	(0.001)	(0.001)	(0.001)
R&D activities	0.151***	0.152***	0.156***	0.158***
	(0.057)	(0.057)	(0.057)	(0.057)
Export activities	-0.030	-0.029	-0.033	-0.036
	(0.060)	(0.060)	(0.059)	(0.060)
Foreign owned	-0.201***	-0.206***	-0.203***	-0.198***
	(0.066)	(0.066)	(0.065)	(0.066)
Demand expectations	0.047*	0.048*	0.047*	0.046
	(0.028)	(0.028)	(0.028)	(0.029)
Price competition	0.016	0.019	0.014	0.021
	(0.024)	(0.024)	(0.024)	(0.024)
Non-price competition	0.042	0.049*	0.040	0.048*
	(0.026)	(0.026)	(0.026)	(0.026)
Information barriers	0.055**	0.061**	0.055**	0.063***
	(0.025)	(0.025)	(0.025)	(0.024)
Organizational barriers	-0.034	-0.031	-0.035	-0.028
	(0.023)	(0.023)	(0.023)	(0.023)
Financing barriers	-0.012	-0.016	-0.013	-0.013
	(0.026)	(0.026)	(0.026)	(0.026)
Adjustment barriers	-0.012	-0.014	-0.011	-0.009
	(0.025)	(0.025)	(0.024)	(0.025)
Energy costs	0.071***	0.074***	0.070***	0.072***
	(0.022)	(0.022)	(0.022)	(0.022)
Environmental awareness	0.126***	0.148***	0.129***	0.152***
	(0.024)	(0.024)	(0.024)	(0.024)
Industry's total adoption intensity	0.068*	0.076**	0.068*	0.071**
	(0.035)	(0.036)	(0.035)	(0.036)
Energy tax			0.101*	
			(0.054)	
Subsidies	-0.121*		-0.127**	
	(0.063)		(0.063)	
Regulation	0.093			
	(0.061)			
Energy price	-0.062		-0.065	
	(0.055)		(0.053)	
Non-political motives	0.263***		0.268***	
	(0.066)		(0.066)	
Current tax only	0.015	-0.003		
	(0.103)	(0.102)		
Expected tax only	0.005	0.006		
	(0.069)	(0.068)		
Time-consistent tax	0.108*	0.120**		
	(0.060)	(0.055)		
Current regulation only			0.145*	0.129
			(0.086)	(0.086)
Expected regulation only			0.055	0.054
			(0.105)	(0.105)
Time-consistent regulation			0.100	0.132**
			(0.064)	(0.059)
Constant	-3.722***	-3.869***	-3.719***	-3.814***
	(0.291)	(0.290)	(0.289)	(0.289)
Industry dummies	yes	yes	yes	yes
N	1234	1234	1234	1234
Pearson chi-square statistics	718.82	732.42	714.40	732.49
Root mse	0.60	0.61	0.59	0.61

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

Table 4: Testing for complementarities between the policy types; fractional logit regressions

Dependent variable	Total adoption fraction	
	(1)	(2)
Firm size	0.159***	0.158***
	(0.016)	(0.017)
Investment intensity	0.063***	0.061***
	(0.015)	(0.015)
Tertiary share	-0.001	-0.001
	(0.001)	(0.001)
R&D activities	0.153***	0.156***
	(0.057)	(0.057)
Export activities	-0.031	-0.033
	(0.060)	(0.060)
Foreign owned	-0.193***	-0.191***
	(0.066)	(0.066)
Demand expectations	0.046	0.046
	(0.028)	(0.028)
Price competition	0.014	0.018
	(0.024)	(0.024)
Non-price competition	0.041	0.045*
	(0.026)	(0.026)
Information barriers	0.053**	0.058**
	(0.025)	(0.025)
Organizational barriers	-0.035	-0.031
	(0.023)	(0.023)
Financing barriers	-0.015	-0.019
	(0.026)	(0.026)
Adjustment barriers	-0.009	-0.012
	(0.025)	(0.025)
Energy costs	0.069***	0.071***
	(0.022)	(0.022)
Environmental awareness	0.127***	0.149***
	(0.024)	(0.024)
Industry's total adoption intensity	0.067*	0.072**
	(0.035)	(0.036)
Energy price	-0.060	
	(0.053)	
Non-political motives	0.264***	
	(0.066)	
t1s0r0	0.166**	0.175***
	(0.067)	(0.065)
t0s1r0	0.013	0.053
	(0.098)	(0.098)
t0s0r1	0.147	0.178*
	(0.091)	(0.091)
t1s1r0	-0.080	-0.041
	(0.119)	(0.118)
t0s1r1	0.044	0.135
	(0.123)	(0.122)
t1s0r1	0.248**	0.277**
	(0.120)	(0.119)
t1s1r1	-0.005	0.091
	(0.107)	(0.102)
Constant	-3.732***	-3.836***
	(0.290)	(0.289)
Industry dummies	yes	yes
N	1234	1234
Pearson chi-square statistics	716.11	725.70
Root mse	0.60	0.60

Reading Aid: t=Energy tax, s=Subsidies; r=Regulation; Combinations of these three binary variables: t0_s1_r1= a firm with Energy tax=0, Subsidies=1 and Regulation=1; t1_s0_r0= a firm with Energy tax=1, Subsidies=0 and Regulation=0; etc; reference group: t0_s0_r0.

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

Table 5: Testing for varying effects for different technology categories; fractional logit regressions

	Energy-saving adoption fraction		Energy/heat generating adoption fraction	
	(1)	(2)	(3)	(4)
Firm size	0.166***	0.163***	0.206***	0.215***
	(0.020)	(0.020)	(0.034)	(0.034)
Investment intensity	0.058***	0.055***	0.132***	0.129***
	(0.018)	(0.018)	(0.031)	(0.031)
Tertiary share	-0.003*	-0.003**	0.002	0.001
	(0.002)	(0.002)	(0.003)	(0.003)
R&D activities	0.207***	0.207***	0.131	0.132
	(0.069)	(0.070)	(0.118)	(0.118)
Export activities	0.004	-0.003	-0.027	-0.025
	(0.072)	(0.072)	(0.124)	(0.125)
Foreign owned	-0.173**	-0.163**	-0.506***	-0.506***
	(0.080)	(0.080)	(0.137)	(0.137)
Demand expectations	0.044	0.040	0.095	0.106*
	(0.034)	(0.034)	(0.059)	(0.059)
Price competition	0.012	0.018	0.064	0.068
	(0.029)	(0.029)	(0.050)	(0.050)
Non-price competition	0.060*	0.068**	-0.022	-0.010
	(0.031)	(0.031)	(0.053)	(0.053)
Information barriers	0.090***	0.101***	-0.076	-0.043
	(0.030)	(0.030)	(0.052)	(0.051)
Organizational barriers	-0.013	-0.005	-0.134***	-0.111**
	(0.028)	(0.028)	(0.048)	(0.048)
Financing barriers	-0.017	-0.017	-0.015	-0.007
	(0.032)	(0.031)	(0.054)	(0.054)
Adjustment barriers	-0.003	0.001	-0.043	-0.039
	(0.030)	(0.030)	(0.051)	(0.051)
Energy costs	0.050*	0.053**	0.109**	0.100**
	(0.027)	(0.027)	(0.046)	(0.047)
Environmental awareness	0.153***	0.178***	0.095*	0.126***
	(0.029)	(0.029)	(0.050)	(0.049)
Industry's efficiency adoption propensity	-0.512	-0.363		
	(0.624)	(0.626)		
Industry's efficiency adoption intensity	0.033	0.020		
	(0.111)	(0.111)		
Industry's generation adoption propensity			2.640***	2.803***
			(0.953)	(0.958)
Industry's generation adoption intensity			-0.026	-0.034
			(0.163)	(0.164)
Energy tax	0.148**		0.066	
	(0.066)		(0.113)	
Subsidies	-0.102		-0.305**	-0.179
	(0.076)		(0.130)	(0.120)
Regulation	0.116	0.167**	0.115	
	(0.074)	(0.069)	(0.127)	
Energy price	-0.096		-0.012	
	(0.065)		(0.111)	
Non-political motives	0.277***		0.380***	
	(0.081)		(0.138)	
Constant	-2.681***	-2.758***	-5.978***	-6.109***
	(0.511)	(0.511)	(0.511)	(0.507)
Industry dummies	yes	yes	yes	yes
N	1234	1234	1234	1234
Pearson chi-square statistics	1057.31	1073.49	3082.82	3133.69
Root mse	0.88	0.89	2.56	2.59

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

Table A.1: Descriptive statistics; based on basic model (column (1) of Table 2; N=1234)

Variable	Mean	Std. Dev.	Min	Max
Total adoption fraction	0.2371475	0.1567377	0.04	1
Firm size	316.1722	1869.613	2	44367.9
Investment intensity	25916.95	81492.32	0	2328270
Tertiary share	0.2063857	0.1885775	0	1
R&D activities	0.3833063	0.486389	0	1
Export activities	0.5105348	0.5000917	0	1
Foreign owned	0.1491086	0.3563399	0	1
Demand expectations	2.611831	0.8395473	1	5
Price competition	3.926256	0.9725717	1	5
Non-price competition	3.249595	0.8974709	1	5
Information barriers	0.1841129	0.9609742	-3.342605	2.919538
Organizational barriers	-0.0022982	0.9838451	-2.603956	3.238627
Financing barriers	0.2003847	0.9110542	-2.956415	2.617919
Adjustment barriers	-0.229218	0.9446763	-1.887901	1.911852
Industry's total adoption intensity	5.944233	0.89924	4.765625	9.675
Energy costs	0.0251216	0.1565577	0	1
Environmental awareness	3.406807	0.9723605	1	5
Energy tax	0.2925446	0.4551155	0	1
Subsidies	0.191248	0.3934433	0	1
Regulation	0.1993517	0.3996749	0	1
Energy price	0.7188006	0.4497668	0	1
Non-political motives	0.1596434	0.3664235	0	1

Table A.2: Correlation matrix; based on basic model (column (1) of Table 2; N=1234)

	Total adoption fraction	Firm size	Investment intensity	Tertiary share	R&D activities	Export activities	Foreign owned	Demand expectations
Firm size	0.3246							
Investment intensity	0.2169	0.1667						
Tertiary share	-0.0085	0.0763	-0.0363					
R&D activities	0.1207	0.2225	0.1047	0.1837				
Export activities	0.0289	0.2056	0.0888	0.1551	0.4919			
Foreign owned	-0.0702	0.1363	-0.0262	0.1508	0.1098	0.2005		
Demand expectations	0.1111	0.0313	0.0965	0.1039	-0.0167	-0.1689	-0.0151	
Price competition	0.0065	0.046	-0.0733	0.0002	-0.0139	0.0291	0.0271	-0.1811
Non-price competition	0.0447	0.0299	0.0042	0.1213	0.0798	0.1026	0.0332	0.0103
Information barriers	0.1432	0.0777	0.0717	-0.0032	-0.002	-0.0495	-0.0436	0.0753
Organizational barriers	-0.0795	-0.0855	-0.0033	-0.04	-0.0036	-0.0131	-0.0272	-0.0325
Financing barriers	-0.0575	-0.0522	-0.0611	-0.0922	0.0445	0.0259	0.0641	-0.0764
Adjustment barriers	-0.0398	-0.0576	-0.0745	-0.0248	-0.0122	0.0268	-0.05	0.0031
Industry's total adoption intensity	0.2291	0.0768	0.2378	-0.0644	-0.0448	-0.127	-0.1033	0.1576
Energy costs	0.1422	-0.1026	0.1575	-0.1638	-0.0554	-0.115	-0.1024	0.0613
Environmental awareness	0.2201	0.0455	0.0311	-0.024	-0.0041	-0.0322	-0.009	0.1161
Energy tax	0.0631	-0.0345	-0.0281	-0.0476	-0.016	-0.0225	0.0059	-0.0528
Subsidies	0.0246	0.0139	-0.0041	0.0287	-0.0316	-0.0473	-0.0069	0.0039
Regulation	0.1422	0.1431	0.063	0.0227	0.0155	0.0057	-0.0551	0.0157
Energy price	0.0079	0.0627	0.0107	-0.0605	0.0482	0.0186	-0.0317	-0.0273
Non-political motives	0.1966	0.0387	-0.0081	-0.0112	-0.0023	-0.0335	-0.0147	0.0223

	Price competition	Non-price competition	Information barriers	Organizational barriers	Financing barriers	Adjustment barriers	Industry's total adoption intensity	Energy costs
Non-price competition	0.0815							
Information barriers	-0.01	0.0146						
Organizational barriers	-0.0378	-0.0215	-0.0431					
Financing barriers	0.0738	-0.0184	-0.1863	-0.1091				
Adjustment barriers	0.0747	0.0025	0.1303	0.0683	0.1047			
Industry's total adoption intensity	-0.1134	-0.0515	0.0928	-0.0501	-0.0596	-0.0768		
Energy costs	-0.0675	-0.1356	0.0437	-0.0114	0.0506	-0.0109	0.3029	
Environmental awareness	-0.0223	0.0406	0.0701	-0.0825	-0.0217	-0.0118	0.1239	0.1334
Energy tax	0.0524	0.0276	0.1667	0.1007	0.092	0.1024	0.0191	0.0392
Subsidies	-0.0373	-0.0595	0.1714	0.055	0.0314	0.0041	0.0524	0.0456
Regulation	-0.0247	0.0081	0.1387	-0.0208	0.0258	0.0208	0.0894	0.0401
Energy price	0.036	-0.0008	0.1578	0.0222	0.1116	0.0162	-0.0605	-0.0352
Non-political motives	0.0217	0.0316	0.1697	0.0281	-0.0082	-0.0154	0.0748	0.0521

	Environmental awareness	Energy tax	Subsidies	Regulation	Energy price
Energy tax	0.0644				
Subsidies	0.0742	0.2218			
Regulation	0.0791	0.1963	0.3453		
Energy price	-0.0127	0.3349	0.0796	0.0775	
Non-political motives	0.2228	0.2109	0.2831	0.2588	0.0856

Table A.3: Test for sample selection

	Heckman selection model		Probit regression
Dependent variable	Intensive adoption yes/no	Adoption yes/no	Intensive adoption yes/no
	(1)	(2)	(3)
Firm size	0.250***	0.248***	0.238***
	(0.039)	(0.024)	(0.032)
Investment intensity	0.112***	0.076***	0.108***
	(0.037)	(0.017)	(0.036)
Tertiary share	-0.002	0.000	-0.002
	(0.003)	(0.002)	(0.003)
R&D activities	0.323***	0.352***	0.303***
	(0.116)	(0.079)	(0.110)
Export activities	-0.080	-0.020	-0.078
	(0.117)	(0.076)	(0.118)
Foreign owned	-0.258*	-0.164*	-0.257*
	(0.132)	(0.089)	(0.133)
Demand expectations	0.032	0.080**	0.029
	(0.055)	(0.037)	(0.055)
Price competition	-0.023	0.081**	-0.024
	(0.047)	(0.032)	(0.047)
Non-price competition	0.049	0.015	0.049
	(0.050)	(0.034)	(0.050)
Information barriers	0.131***	0.204***	0.128***
	(0.050)	(0.030)	(0.049)
Organizational barriers	-0.060	0.018	-0.060
	(0.046)	(0.030)	(0.046)
Financing barriers	-0.006	0.326***	-0.017
	(0.059)	(0.031)	(0.051)
Energy costs	0.095**	-0.010	0.095**
	(0.043)	(0.030)	(0.043)
Environmental awareness	0.304***	0.195***	0.295***
	(0.051)	(0.029)	(0.048)
Industry's total adoption intensity	0.104	0.145***	0.096
	(0.067)	(0.056)	(0.066)
Adjustment barriers		-0.335***	-0.020
		(0.031)	(0.049)
Constant	-5.029***	-3.769***	-4.795***
	(0.759)	(0.418)	(0.582)
Industry dummies	yes	yes	yes
N	2285		1234
Wald chi2	117.12***		207.99***
Log likelihood	-1776.48		-555.59
LR test of rho=0: Prob > chi2	0.64		

Table A.4: Non-political motives in more detail; fractional logit regressions

Dependent variable	Total adoption fraction					
	(1)	(2)	(3)	(4)	(5)	(6)
Firm size	0.156***	0.156***	0.154***	0.161***	0.163***	0.163***
	(0.017)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
Investment intensity	0.060***	0.060***	0.060***	0.063***	0.061***	0.062***
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
Tertiary share	-0.001	-0.001	-0.001	-0.002	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
R&D activities	0.143**	0.141**	0.150***	0.147**	0.152***	0.145**
	(0.057)	(0.057)	(0.057)	(0.057)	(0.057)	(0.057)
Export activities	-0.033	-0.032	-0.031	-0.030	-0.036	-0.029
	(0.060)	(0.060)	(0.060)	(0.060)	(0.060)	(0.060)
Foreign owned	-0.198***	-0.199***	-0.206***	-0.200***	-0.198***	-0.196***
	(0.066)	(0.066)	(0.066)	(0.066)	(0.066)	(0.066)
Demand expectations	0.045	0.043	0.047*	0.043	0.045	0.045
	(0.028)	(0.028)	(0.028)	(0.029)	(0.029)	(0.028)
Price competition	0.018	0.020	0.023	0.016	0.018	0.021
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
Non-price competition	0.046*	0.051**	0.052**	0.050*	0.049*	0.047*
	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)
Information barriers	0.057**	0.052**	0.061**	0.065***	0.069***	0.060**
	(0.025)	(0.025)	(0.024)	(0.024)	(0.024)	(0.025)
Organizational barriers	-0.033	-0.033	-0.031	-0.026	-0.023	-0.031
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)
Financing barriers	-0.020	-0.022	-0.022	-0.012	-0.010	-0.012
	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)
Adjustment barriers	-0.011	-0.004	-0.006	-0.009	-0.007	-0.007
	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)
Energy costs	0.074***	0.075***	0.073***	0.075***	0.076***	0.074***
	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
Environmental awareness	0.117***	0.120***	0.132***	0.137***	0.141***	0.148***
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
Industry's total adoption intensity	0.061*	0.062*	0.068*	0.069*	0.071**	0.072**
	(0.036)	(0.036)	(0.036)	(0.036)	(0.036)	(0.036)
Energy tax	0.093*					
	(0.055)					
Subsidies	-0.136**					
	(0.063)					
Regulation	0.057					
	(0.063)					
Energy price	-0.072					
	(0.054)					
Voluntary agreements	0.218***	0.222***	0.252***			
	(0.058)	(0.056)	(0.054)			
Demand pull	0.076	0.074		0.129***		
	(0.049)	(0.049)		(0.047)		
Intrinsic motivation	0.059	0.051			0.111**	
	(0.054)	(0.054)			(0.052)	
Expected energy shortage	0.074	0.063				0.110**
	(0.052)	(0.052)				(0.050)
Constant	-3.718***	-3.780***	-3.790***	-3.801***	-3.849***	-3.845***
	(0.291)	(0.289)	(0.288)	(0.290)	(0.290)	(0.289)
Industry dummies	yes	yes	yes	yes	yes	yes
N	1234	1234	1234	1234	1234	1234
Pearson chi-square statistics	721.94	730.83	731.88	737.60	738.52	736.15
Root mse	0.60	0.61	0.61	0.61	0.61	0.61

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

Table A.5: Subsidies in more detail; fractional logit regressions

Dependent variable	Total adoption fraction				
	(1)	(2)	(3)	(4)	(5)
Firm size	0.160***	0.160***	0.162***	0.158***	0.162***
	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
Investment intensity	0.064***	0.064***	0.062***	0.064***	0.062***
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
Tertiary share	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
R&D activities	0.153***	0.152***	0.154***	0.153***	0.154***
	(0.057)	(0.057)	(0.057)	(0.057)	(0.057)
Export activities	-0.029	-0.029	-0.031	-0.027	-0.031
	(0.060)	(0.060)	(0.060)	(0.060)	(0.060)
Foreign owned	-0.205***	-0.206***	-0.202***	-0.201***	-0.201***
	(0.066)	(0.066)	(0.066)	(0.066)	(0.066)
Demand expectations	0.050*	0.050*	0.046	0.050*	0.046
	(0.028)	(0.028)	(0.029)	(0.028)	(0.029)
Price competition	0.016	0.017	0.020	0.015	0.020
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
Non-price competition	0.042	0.042	0.048*	0.043*	0.049*
	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)
Information barriers	0.056**	0.055**	0.073***	0.054**	0.071***
	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)
Organizational barriers	-0.033	-0.034	-0.024	-0.035	-0.025
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)
Financing barriers	-0.011	-0.011	-0.009	-0.013	-0.010
	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)
Adjustment barriers	-0.011	-0.011	-0.009	-0.011	-0.009
	(0.025)	(0.024)	(0.025)	(0.025)	(0.025)
Energy costs	0.072***	0.072***	0.074***	0.071***	0.074***
	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
Environmental awareness	0.128***	0.128***	0.152***	0.126***	0.151***
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
Industry's total adoption intensity	0.067*	0.067*	0.075**	0.068*	0.074**
	(0.035)	(0.035)	(0.036)	(0.035)	(0.036)
Energy tax	0.103*	0.103*		0.094*	
	(0.055)	(0.055)		(0.054)	
Regulation	0.093	0.091		0.081	
	(0.061)	(0.061)		(0.061)	
Energy price	-0.058	-0.058		-0.060	
	(0.053)	(0.053)		(0.054)	
Non-political motives	0.263***	0.261***		0.253***	
	(0.066)	(0.066)		(0.066)	
CO2 reduction subsidies	-0.108	-0.118**	-0.028		
	(0.066)	(0.056)	(0.053)		
Energy efficiency subsidies	-0.018			-0.073	0.002
	(0.065)			(0.055)	(0.052)
Constant	-3.735***	-3.738***	-3.841***	-3.727***	-3.839***
	(0.290)	(0.290)	(0.289)	(0.290)	(0.290)
Industry dummies	yes	yes	yes	yes	yes
N	1234	1234	1234	1234	1234
Pearson chi-square statistics	718.18	718.46	737.67	720.96	738.54
Root mse	0.60	0.60	0.61	0.60	0.61

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