Journal of Cleaner Production xxx (2016) 1–16

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Intra-firm diffusion of green energy technologies and the choice of policy instruments

Tobias Stucki*, Martin Woerter**

ETH Zurich, KOF Swiss Economic Institute, CH-8092 Zurich, Switzerland

ARTICLE INFO

Article history:
Received 19 October 2015
Received in revised form
23 March 2016
Accepted 28 April 2016
Available online xxx

Keywords:
Technology adoption
Innovation
Policies
Intra-firm diffusion
Survey data

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.

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 CO_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 an energy-saving technology, it is likely that in the course of the time further 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.

* Corresponding author. Tel.: +41 44 632 63 07.
** Corresponding author. Tel.: +41 44 632 51 51.
E-mail addresses: stucki@kof.ethz.ch (T. Stucki), woerter@kof.ethz.ch (M. Woerter).

http://dx.doi.org/10.1016/j.jclepro.2016.04.144
0959-6526/

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 policy-making 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 equal 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, 1989).

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 leads 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

Please cite this article in press as: Stucki, T., Woerter, M., Intra-firm diffusion of green energy technologies and the choice of policy instruments, Journal of Cleaner Production (2016), http://dx.doi.org/10.1016/j.jclepro.2016.04.144