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The two faces of market support—How deployment policies affect technological exploration and exploitation in the solar photovoltaic industry

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ABSTRACT

The recent years have seen a strong rise in policies aiming to increase the diffusion of clean energy technologies. While there is general agreement that such deployment policies have been very effective in bringing technologies to the market, it is less understood how these policies affect technological innovation. To shed more light on this important question, we conducted comparative case studies with a global sample of 9 firms producing solar photovoltaic (PV) modules, complemented by in-depth interviews with 16 leading PV industry experts. We propose that, on the one hand, policy-induced market growth serves as an important catalyst for innovative activity as it raises the absolute level of firm investments in technological exploration. On the other hand, however, deployment policies create an incentive for firms pursuing more mature technologies to shift their balance between exploitation and exploration toward exploitation. Firms focusing on less mature technologies cannot tap the potentials of exploitative learning to the same extent as those with more mature technologies. Therefore, stimulating strong market growth may raise the barrier to market entry for less mature technologies. We conclude that, when designing deployment policies, great care should be taken to avoid adverse effects on technological diversity and a premature lock-in into more established technologies.

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1. Introduction

Reconciling economic objectives with environmental concerns requires decoupling economic growth from its negative consequences such as resource depletion or the emission of greenhouse gases. A major lever to achieve this goal is the use of clean energy technologies. However, currently, many of these technologies are still at an early stage of development and not yet cost competitive with long-established fossil fuel-based energy technologies (IEA, 2011). Therefore, a question of significant importance is how public policies can foster technological progress in the field of clean energy technologies (e.g. Mowery et al., 2010).

While until the year 2000 government support largely focused on the direct funding of research and development (R&D), during the last ten years there has been an increasing focus on so-called deployment policies, targeted at diffusing clean energy technologies into the market. For example, to date more than 60 countries worldwide have introduced feed-in tariffs which grant producers of clean power a fixed price per unit of electricity (REN21, 2011). In a rising number of countries, the funding dedicated to deployment policies by far exceeds direct political incentives for R&D – for example, by a factor of around 40 in Germany (50hertz et al., 2010; BMU, 2010).

The literature on environmental policy suggests that, besides having a positive effect on diffusion, deployment policies can 'induce' innovation (e.g. Del Río González, 2009; Porter and van der Linde, 1995). Furthermore, quasi-evolutionary approaches to innovation policy recommend that regulators make use of deployment policies to create niche markets for technologies. Such niches are assumed to foster innovation in emerging technologies by shielding them from competition with established regimes (e.g. Kemp et al., 1998). However, up to this point the empirical literature provides only limited insights into the *detailed mechanisms* through which deployment policies affect innovation on an actor level. Studies in environmental economics generally investigate the innovation effect of deployment policies on a rather aggregate level of analysis, e.g. the sector (Cleff and Rennings, 1999). Empirical evolutionary research on deployment policies usually assumes a systems perspective without explicitly focusing on how these policies influence specific actors, such as firms, in their decisions to invest in innovative activities (Nill and Kemp, 2009).

A recent study by Nemet (2009) underscores the importance of analyzing the innovation effects of deployment policies on a more disaggregated level. Studying patenting activity in the wind industry, Nemet suggests that policy-induced market growth may have incentivized technology producers to 'exploit' existing products to benefit from learning-by-doing and economies of scale,

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while simultaneously setting a disincentive to 'explore' alternative technological options. A strong focus on technological exploitation relative to exploration, in turn, is likely to yield less radical innovations and might raise the likelihood of technological lock-ins (Malerba, 2009; Sandén, 2005). Given that it remains unclear whether existing technological trajectories are sufficient to meet future economic, social and ecological goals, it seems advisable to avoid a premature lock-in into particular technologies (Stirling, 2010). Therefore, analyzing the detailed mechanisms through which deployment policies affect technological exploitation and exploration on the firm level could bear important implications for theory and praxis. Although the literature on organizational learning has identified various antecedents of firm-level exploration/exploitation, such as a firm's slack resources, thus far there are no empirical studies available that investigate the impact of public policy (Lavie et al., 2010).

With this paper, we contribute to a more nuanced picture of how deployment policies induce innovation. In contrast to previous studies, we choose the firm as the unit of analysis and present systematic empirical data that describe *how deployment policies affect corporate investments in technological exploration and exploitation.* Following an inductive approach, we derive testable propositions, which are based on findings from in-depth interviews with 24 corporate managers in 9 European, US, Chinese and Japanese firms producing solar photovoltaic (PV) modules. These case studies are complemented by interviews with 16 leading PV industry experts. Besides providing a rich description of the mechanisms at work, our approach allows us to examine how deployment policies affect technological competition between more and less mature PV technologies.

The remainder of this paper is structured as follows: Section 2 provides an overview of past studies dealing with the innovation effect of deployment policies as well as the literature on exploitation and exploration. Furthermore, the initial theory framework as developed at the outset of the study is presented. Sections 3 and 4 introduce the research case and method. The results of our study are presented in Section 5, followed by a discussion of implications for theory and policy makers (Section 6). The paper concludes with a description of limitations, suggestions for future research and a brief summary of the main results.

2. Literature review

2.1. Deployment policies and their effect on technological innovation

The notion that demand-side regulation can serve as an important driver of technological innovation has been discussed in two separate streams of research: the literature on environmental policy and quasi-evolutionary approaches to innovation policy.

The literature on environmental policy argues that environmentally benign innovation suffers from a so-called 'double externality problem' since the environmental side-effects of economic activity are not sufficiently reflected in market prices and, in the face of knowledge spillovers, firms may systematically underinvest in innovation (Jaffe et al., 2005; Rennings, 2000). In order to correct for these market failures, environmental policy scholars suggest that policy makers introduce regulatory measures to foster the adoption of environmental technologies and enhance innovation (Horbach, 2008). In this context, scholars have invested considerable effort in evaluating different instruments that directly or indirectly affect technology deployment, such as technology standards, tradable permits or feed-in tariffs (Jaffe et al., 2002; Jänicke and Lindemann, 2010). Although studies show a remarkable degree of ambiguity in their assessment of the individual instruments, there is a widespread consensus that demand triggered by deployment policies induces innovation (Newell et al., 1999). These findings are in line with the 'weak version' of the so-called Porter Hypothesis, which suggests that "properly designed environmental standards can trigger innovation" (Porter and van der Linde, 1995, p. 98). Contradicting conventional neo-classical wisdom, Porter and van der Linde (1995) argue that environmental regulation may enhance innovation by signaling companies about resource inefficiencies and reducing investment uncertainties.

In quasi-evolutionary approaches, deployment policies are not only seen as a means to correct for externalities or managerial information deficiencies in an otherwise efficient market (Metcalfe, 1994; Nill and Kemp, 2009). It is reasoned that, more generally, policy makers can foster technological learning and may help to break technological lock-ins (Malerba, 2009). Technological lock-ins emerge as a result of a variety of factors, such as increasing returns to scale, network effects or industry standards (Arthur, 1989; David, 1985). While, on the positive side, these factors contribute to system stability and efficiency, technological search under a lock-in situation becomes highly localized and incremental in nature (Unruh, 2000). Since this precludes the development and diffusion of radically different, economically or ecologically superior technological alternatives, deployment policies have been recommended to create niche markets for environmental technologies where these technologies can advance without standing in direct competition with established technological regimes (Faber and Frenken, 2009; Kemp et al., 1998; Smith et al., 2005; Unruh, 2002).

While much progress has been made in describing and measuring *the effects of* deployment policies, the understanding of *the exact mechanisms through which* deployment policies induce innovation is much less well developed. Studies in the field of environmental economics often use highly aggregated measures of innovation, such as patents or R&D investments on the sector-level (Cleff and Rennings, 1999), and provide little insight into the firm-level dynamics linking deployment policies with the observed positive innovation effect (Ambec et al., 2011). Furthermore, work in the field of environmental policy usually focuses on the firms directly affected by the regulation (e.g. for pollution control) rather than those supplying the required environmental technologies, for which deployment policies stimulate product sales and may create incentives for innovation (Schmidt et al., 2012). Quasi-evolutionary approaches to policy have a much stronger foundation in the micro processes of technical change. However, empirical studies usually take a systems perspective, not explicitly focusing on how policy may incentivize specific actors, such as firms, to invest in innovative activities (Dosi and Marengo, 2007; Nill and Kemp, 2009). Recent studies suggest that studying the link between deployment policies and technological innovation on a more disaggregated level, e.g. the firm level, may be critical since innovation can result from different modes of technological learning which may be differently triggered by deployment policies (Hendry and Harborne, 2011; Malerba, 2009).

2.2. Two modes of technological learning: exploration and exploitation

March (1991, p. 71) suggests that, in general, firms can choose between two basic modes of learning: (1) Exploration, which he defines as "search, variation, risk-taking, experimentation, play, flexibility, discovery, and innovation", and (2) exploitation which includes terms like "refinement, choice, production, efficiency, selection, implementation and execution". He claims that, in order to survive in the longer term, organizations have to make use of both exploration and exploitation. At the same time, however, he

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