THE ROLE OF DEPLOYMENT POLICIES IN FOSTERING INNOVATION FOR CLEAN ENERGY TECHNOLOGIES – INSIGHTS FROM THE SOLAR PHOTOVOLTAIC INDUSTRY

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Published in *Business & Society*

Please cite this article as: Hoppmann, J. (2015). The Role of deployment policies in fostering innovation for clean energy technologies: Insights from the solar photovoltaic industry. *Business & Society*, 54(4), 540-558.

ABSTRACT

In recent years, governments in a large number of countries have introduced so-called deployment policies to foster the diffusion of clean energy technologies. While there is little doubt that these demand-side measures have been very effective in raising the share of clean electricity generation, currently much less is known about how deployment policies affect – and are affected by – technological innovation beyond the mere diffusion of existing technologies. Against this backdrop, this dissertation abstract and commentary presents the dissertation work of Dr. Joern Hoppmann. Based on a discussion of deployment policies as a means for addressing pressing societal issues, the dissertation abstract describes four essays that provide a detailed account of the role that these policies play for technological learning in the solar photovoltaic industry. The theoretical background, methods and main findings of each of the essays are briefly summarized. Building upon this, this abstract discusses implications for managers and policy makers in terms of how to improve the design of deployment policies and navigate businesses in policy-induced markets.

Keywords: Deployment policy, ambidexterity, absorptive capacity, environmental innovation, innovation policy, solar photovoltaic power, renewable energy

INTRODUCTION

A question of major importance is how policy makers can foster technological progress in clean energy technologies in order to alleviate adverse environmental impacts of the energy sector, reduce the dependence on fossil fuels, and create new jobs in dynamic high-tech industries. Until the end of the 1980s, government support of clean energy technologies largely focused on the direct funding of R&D. However, particularly since the 1990s, many countries have introduced so-called deployment policies that aim to foster the diffusion of clean energy technologies in the market. In an increasing number of countries, demand-side incentives for clean energy technologies now outstrip investments in public R&D. Market support for solar photovoltaic (PV) power in Germany, for example, has grown significantly over the past decade, now exceeding public R&D funding by a factor of 120 (see Figure 1).

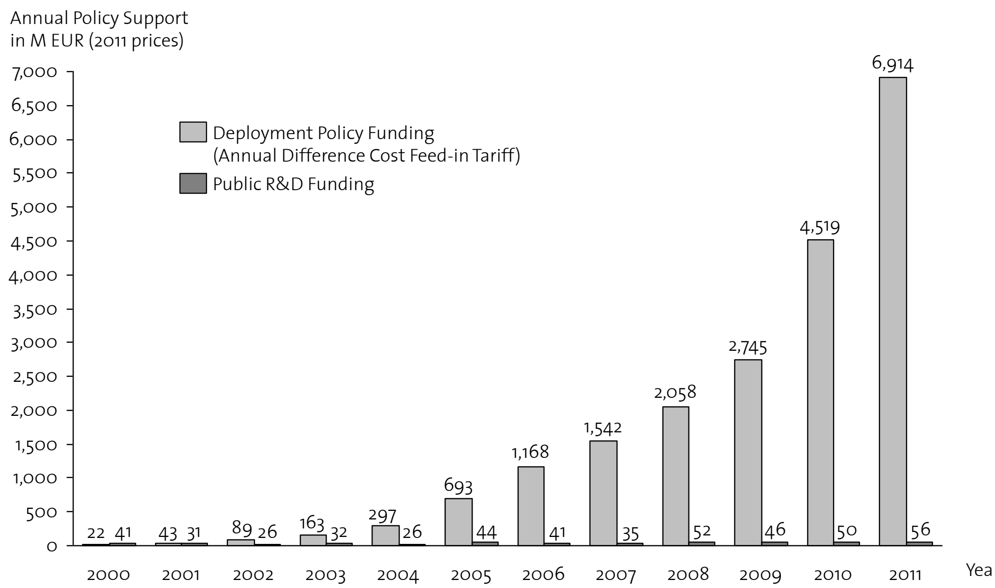

FIGURE 1: Annual policy support for solar photovoltaic power in Germany (data from BDEW, 2011; IEA, 2012)

Deployment policies can take different forms, ranging from fiscal incentives and public finance to market regulations (IRENA, 2012). Fiscal incentives include grants or tax credits that lower the initial cost of technology investment for operators of clean energy plants. Public finance incentivizes the use of clean energy technologies by providing guarantees or low-interest loans. Instruments for market regulation, in turn, can be divided into volume- and price-driven instruments. Volume-based instruments, such as renewable portfolio standards or quotas, set targets for the amount of renewable electricity a sector or firm needs to produce at a particular point in time. Usually, these instruments are designed in a way that, in case of missing the quota, the respective entity is required to pay a penalty, thereby creating an economic incentive for investments in clean energy sources. In contrast, price-based instruments, such as feed-in tariffs, incentivize the use of clean energy technologies by guaranteeing power generators a fixed price higher than market prices at which they can feed renewable electricity into the grid. Overall, by early 2012, 109 countries had implemented policies to support the generation of renewable electricity (IRENA, 2012). As shown in Figure 2, the instrument of feed-in tariffs has reached particularly widespread diffusion and is now used in more than 65 countries in the world (REN21, 2012).

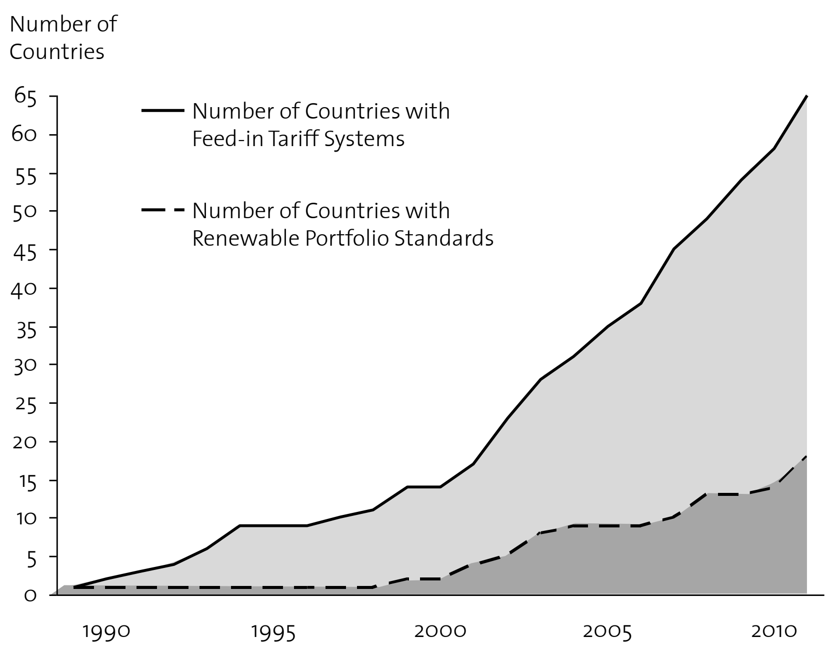

FIGURE 2: Number of countries with feed-in tariff systems and renewable portfolio standards (data from REN21, 2011, 2012)

Mainly due to demand-side subsidies, the installed renewable power generation capacity (excluding hydro power) has risen by 144 percent in only six years, from 160 GW in 2005 to 390 GW in 2011 (REN21, 2005, 2012). Deployment policies have thus proven a highly effective means of bringing clean energy technologies to the market in the short to medium term. However, at the same time many clean energy technologies remain far from being cost competitive with fossil fuel based energy sources. Supporting the widespread deployment of technologies that are not economically viable requires considerable public funds, which are generally not available in developing countries. Hence, for renewable energies to assume a large share in the global market for energy technologies over the long term, it seems indispensable that clean energy technologies reach a cost level at which they can compete with conventional energy sources without policy support. Given the strong focus of policy makers on demand-side instruments in recent years, a critical question becomes whether and to which extent deployment policies have promoted technological advancement in clean energy technologies beyond a mere diffusion of existing technologies. If the effect of deployment policies was indeed limited to bringing existing concepts to the market, policy makers might be better advised to invest their funds in research and development to bring technologies closer to competitiveness instead of subsidizing their widespread use.

Amid the strong prevalence of deployment policies in recent years and the need for technological progress in clean energy technologies, this thesis addresses the overarching research question of *how deployment policies affect, and are affected by, innovation in clean energy technologies*. For this purpose, this work draws on both qualitative and quantitative methods to analyze the dynamics and effects of deployment policies in the solar PV industry. Figure 3 shows the overarching research framework underlying this work. As can be seen, this work puts a particular emphasis on trying to better understand the detailed effect of deployment policies on firms and their investments in technological learning as a variable mediating the relationship between policy and technological innovation. Moreover, as an important difference to previous studies, this research does not assume policies to be exogenously given but studies how they are affected by – rather than simply affect – technological change.

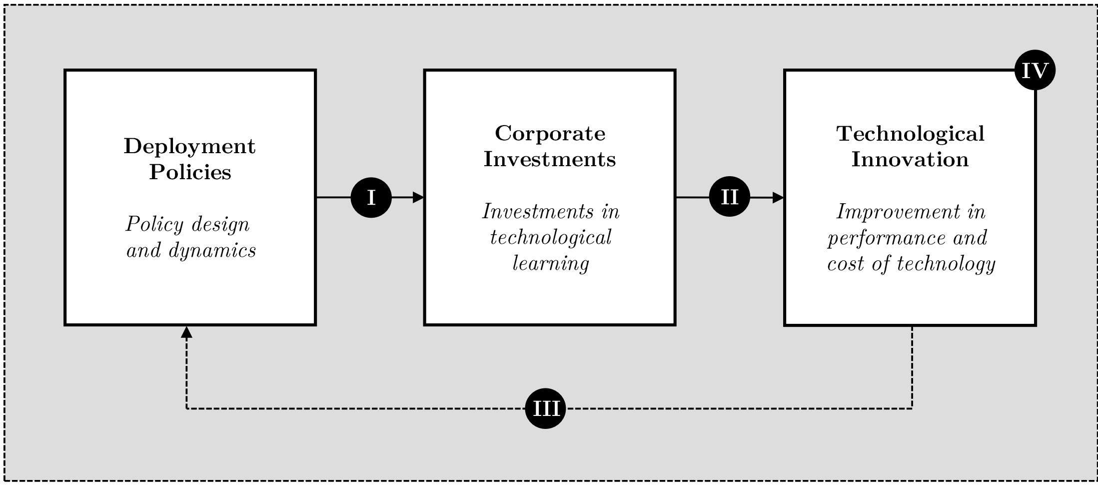

FIGURE 2: Research framework

THEORETICAL BACKGROUND AND OBJECTIVES

To examine the link between deployment policies and technological innovation, this thesis contains four essays, each of which addresses a particular gap in the extant literature (see black markers in Figure 2). The first essay (see Hoppmann, Peters, Schneider, & Hoffmann, 2013) scrutinizes the detailed mechanisms through which deployment policies affect technological learning at the firm level. There is a broad consensus in the economic literature that deployment policies can induce innovation (e.g., Jaffe, Newell, & Stavins, 2004). Yet, currently, it remains unclear how deployment policies affect corporate investments into different modes of learning, such as exploration and exploitation (March, 1991). A recent study by Nemet (2009) suggests that policy-induced market growth may incentivize technology producers to *exploit* existing products to benefit from learning-by-doing and economies of scale, while simultaneously setting a disincentive to *explore* alternative technological options. A strong focus on exploitation to the detriment of exploration, however, may raise the likelihood that an industry becomes locked into a specific technology (Malerba, 2009). Given that in the extant literature deployment policies are primarily seen as instruments for *breaking* lock-ins, the idea that they might also *contribute to their* *occurrence* calls for a more detailed investigation of the exact mechanisms through which deployment policies affect firms within an industry. While anecdotal evidence suggests that deployment policies affect the degree to which firms focus on technological exploitation and exploration, it remains unclear whether deployment policies in fact induce exploitative behavior and enhance the risk of a technological lock-in. Although the literature on organizational learning has identified various antecedents of firm-level exploration and exploitation (see Section 2.2), thus far there are no empirical studies available that investigate the impact of public policy (Lavie, Stettner, & Tushman, 2010).

The second essay sheds additional light on the link between corporate investments in technological learning and technological innovation. More specifically, the essay addresses the question to what extent and through which channels innovation in environmental technologies is driven by inter-firm knowledge spillovers. The degree to which innovation in environmental technologies is driven by knowledge spillovers has important implications for the debate on whether corporate investments in environmental innovation can spur the competitive advantage of firms. In the literature a number of scholars have suggested that firms that take a proactive stance towards investments in innovation for environmental technologies are able to reap economic benefits (Buysse & Verbeke, 2003; Shrivastava, 1995). However, if knowledge generated through innovation spills over to other firms, this undermines the competitive advantage that a firm may be able to generate through investments in innovation (McEvily & Chakravarthy, 2002; Wernerfelt, 1984). Currently, we lack systematic evidence of the antecedents of inter-firm knowledge spillovers in the case of environmental technologies. The extant literature suggests that a particularly important factor affecting the degree to which a firm can benefit from other firms' knowledge is its absorptive capacity (Cohen & Levinthal, 1990). While in the past absorptive capacity has usually been measured by drawing upon the company's investments in research and development, recent research suggests that the means of acquiring firm-external knowledge might differ over time. For example, based on a study of copper interconnect technology for semiconductor chips, Lim (2009) suggests that the type of knowledge firms absorb changes over the technology life-cycle from general scientific knowledge to knowledge embedded in tools and processes. Therefore, essay II tests whether knowledge spillovers contribute to the cost-to-performance ratio of environmental technologies and whether – besides the well-known lever of investments in R&D (Cohen & Levinthal, 1990) – a firm's absorption of external knowledge is driven by investments in standardized manufacturing equipment.

Together, the first two essays shed light on the detailed effects of deployment policies on technological innovation. However, they do not yet provide any insights into the reverse relationship, i.e., how technological change and related uncertainties affect the dynamics and design of deployment policies. The literature on innovation systems suggests that technological change results from the complex interplay of a large number of actors (e.g., firms, policy makers), networks (formal and informal), technologies (e.g., knowledge and artifacts) and institutions (e.g., norms, values or regulations) within a socio-technical system (Carlsson & Stankiewicz, 1991; Edquist, Fagerberg, Mowery, & Nelson, 2005). It is argued that, to account for this complexity, policy makers should follow systemic approaches when trying to foster technological change (Wieczorek & Hekkert, 2012). Systemic policy making implies careful analysis of the socio-technical system to identify potential bottlenecks, so-called 'system failures' or 'system problems', and devising measures targeted at their removal (e.g., Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008; Edquist, 2011; Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007). Yet, currently, it remains unclear how technological uncertainties and the complexity of socio-technical systems might prevent policy makers from targeted interventions in socio-technical systems (Bergek et al., 2008). The literature on policy learning has stressed the emergent nature of policy, investigating factors driving or inhibiting adaptation of policies (Bennett & Howlett, 1992; Lindblom, 1959). However, existing studies have typically focused on factors residing in the political system as antecedents of policy evolution rather than the characteristics and dynamics of the system to be intervened in. Amid a lack of research on this issue, essay III (see Hoppmann, Huenteler, & Girod, 2014) therefore investigates how the complex dynamics of socio-technical systems shape the process of policy interventions targeted at inducing technological change.

Finally, the fourth essay (see Hoppmann, Volland, Schmidt, & Hoffmann, 2014) studies the effect of policy-induced innovation on the economic viability of technologies complementary to those directly benefiting from market support. The literature streams on complex products and systems (Hobday, 1998) and large technical systems (Hughes, 1979) provide many examples for technologies, such as airplanes, computers or the electricity system, that consist of a large number of interconnected components. It is pointed out that, due to the interdependencies and complementarities between these components, changes in one part of the system usually have direct effects on others or even require changing the entire product architecture (Henderson & Clark, 1990). Lissoni and Metcalfe (1994, p. 107), for example, suggest that "[c]ompatibility, inter-relatedness and co-development are emerging as important themes in modern diffusion research. Furthermore, a single innovation is no longer seen as the appropriate unit for diffusion analysis. Rather what is being diffused is often a sequence of innovations with an evolving design configuration which itself develops in response to competing and complementary configurations". Despite the observation that in many cases technologies are linked to build larger technological systems, extant studies have usually focused on investigating the effect of deployment policies with regard to the particular technology that is directly targeted by policy makers. It seems likely that the diffusion of the technology and the related improvements in its cost-to-performance ratio affects complementary technologies. Since these technologies are often of critical importance to the performance of the overall system, research seems warranted that elaborates on how policy-induced technological change affects the economic viability of complementary technologies.

RESEARCH SETTING AND METHODS

All four essays draw on empirical data from the solar photovoltaic (PV) industry. PV offers major technological potential for clean electricity generation. However, due to the high costs of the technology, the PV industry is still strongly dependent on deployment policies, making it an ideal case to study their effects and dynamics. In line with the different phenomena to be investigated, this dissertation applies a mix of both qualitative and quantitative methods (see Table 1).

TABLE 1: Methods and data sources used in essays

Essay	Title	Method	Data Sources	Geogr. Scope	Time Scope
I	The Two Faces of Market Support – How Deployment Policies Affect Technological Exploration and Exploitation in the Solar Photovoltaic Industry	Qualitative: Comparative case study	Data from interviews with 24 managers of 9 firms producing PV modules and 16 PV industry experts	Global	2004 – 2011
II	The Role of Inter-Firm Knowledge Spillovers for Innovation in Environmental Technologies – Evidence from the Solar Photovoltaic Industry	Quantitative: Panel data regression	Data from annual reports of 23 publicly listed producers of wafer-based crystalline silicon PV cells and industry reports	Global	2000 – 2011
III	Compulsive Policy-Making – The Evolution of the German Feed-in Tariff System for Solar Photovoltaic Power	Qualitative: Longitudinal case study	Data from archival documents of the German Bundestag, secondary data sources and interviews with industry experts	Germany	1991 – 2012
IV	The Economic Viability of Battery Storage for Residential Solar Photovoltaic Systems – A Review and a Scenario-Based Optimization Model	Quantitative: Techno-economic model	Secondary data on technological and economic parameters of PV and storage technologies	Germany	2011 – 2020

To investigate the mechanisms connecting deployment policies and firm-level technological learning, essay I draws on comparative case study methodology (Eisenhardt, 1989). Data were gathered using semi-structured interviews with 24 managers of nine European, American, Japanese and Chinese firms producing PV modules as well as 16 expert interviews. After transcribing the interview data from records or handwritten notes, the data were analyzed using analytical induction (Manning, 1982). For this purpose, the interview transcripts were investigated using the qualitative data analysis software ATLAS.ti to refine an initial theory framework and derive a set of testable propositions.

To examine the role of spillovers for innovation in solar PV, essay II uses panel data regression analysis on data from 23 publicly listed producers of wafer-based crystalline silicon PV cells. Data was gathered from company annual reports, industry reports and the PV industry magazine ‘Photon’. Since there is a long line of literature describing the channels and effects of knowledge spillovers, in contrast to essay I, the main goal of essay II is not to build new theory but to test a number of well-founded hypotheses.

To study the relationship between technological innovation and policy design and dynamics, similar to essay I, essay III employs a qualitative case study approach. Due to the long history of the instrument, the German feed-in tariff (FIT) system for solar photovoltaic power from 1991 to the beginning of 2012 was chosen as a research case. Data were obtained from the archive of the German national parliament (Bundestag), secondary data sources and interviews with industry experts. The more than 500 documents were subsequently analyzed using qualitative content analysis to understand a) legislative changes, b) the drivers behind them, and c) the effects changes have had on the broader socio-technical system. The insights generated in this process, in turn, served as the basis for developing a process model which describes how policy-induced technological change drives changes in the design of policies.

Finally, to study the effect of deployment policies on complementary technologies, essay IV investigates when and under which conditions battery storage will be economically viable in residential PV systems without demand-side subsidies for an economically optimized system configuration. In contrast to the other essays in this dissertation, the time scope of this analysis is forward-looking. To address the research question, therefore, a scenario-based, techno-economic model was used that simulates the profitability of storage for a residential PV system in Germany under eight different electricity price scenarios from 2011 to 2020. Comparing the optimal storage and PV system size for different scenarios, allowed for an assessment of the influence of external factors, such as deployment-driven decreases in PV investment costs, electricity wholesale and retail prices, on the economic viability of storage for residential PV systems.

KEY FINDINGS AND CONTRIBUTIONS TO THE LITERATURE

This dissertation makes four major contributions to the extant literature. First, essay I (see Hoppmann et al., 2013) shows that deployment policies are powerful means to spur firm-level technological learning but that they differentially affect learning in firms pursuing more and less mature technologies. For firms pursuing more mature PV technologies, e.g., wafer-based crystalline silicon PV, deployment policies create an incentive to invest in production capacity and sell products in the emerging market. The income the firms generate this way is used to finance investments in both R&D (i.e., exploration) and further increases in production capacity (i.e., exploitation). The managers we interviewed in the course of our case study underscored that revenues generated from policy-induced market growth represent an important income stream to finance exploration activities. At the same time, however, we find that the stronger the policy-induced market growth, the more firms will be inclined to raise their investments in production to a larger degree than their investments in R&D for three reasons: First, given a certain level of supply, higher policy-induced demand leads to larger profit margins in an industry, which reduces the immediate pressure on firms to engage in risky, long-term R&D. Second, in times of high market growth, firms may experience a bottleneck in scarce human resources, requiring them to shift personnel from R&D to production. Third, in the PV industry, deployment policies have opened up markets for firms that supply specialized production equipment. The availability of off-the-shelf equipment has significantly facilitated production investments of firms and in some cases created a disincentive for firms producing the cells and modules to invest in their own R&D. For firms pursuing less mature technologies, i.e., thin-film or emerging PV technologies, deployment policies are important as they raise investor interest in an industry. Since for these firms venture capital constitutes an important source of funding, deployment policies are a critical enabler for investments in both R&D and production. Yet, because firms pursuing less mature technologies often do not possess a physically mature product or production equipment, they are usually not in a position to directly benefit from policy-induced demand. The limited possibility of firms pursuing less mature technologies to benefit from exploitation, e.g. through economies of scale, puts them at a disadvantage compared to firms pursuing more mature technologies in times of policy-induced market growth. As a result, strong policy-induced market growth raises the risk of a technological lock-in into more mature technologies.

Second, essay II presents empirical evidence that firm-level innovation in PV technologies is driven by knowledge spillovers from other firms. In accordance with the literature on absorptive capacity, absorption of external knowledge is positively associated with firms' prior knowledge generated through R&D. However, at the same time, the essay provides evidence that, besides investments in R&D, investments in production equipment have driven inter-firm knowledge spillovers in the PV industry. This finding lends support for previous studies that suggest the emergence of standardized equipment has played an important role in driving changing leadership positions in the PV industry. Equipment manufacturers have integrated knowledge into their products that was developed in close collaboration with primarily Western manufacturers of PV cells. By exporting the equipment to China and Taiwan, producers of PV cells in these countries were able to tap this knowledge and produce PV cells at a high quality and low cost without having to make large investments in R&D. Moreover, the findings provide a more nuanced perspective on the question of whether and when environmental innovation leads to longer-term competitive advantage (Porter & van der Linde, 1995; Shrivastava, 1995). They suggest that to investigate the link between environmental innovation and competitive advantage, the literature needs to investigate the prevalence, origins and effects of knowledge spillovers. By pointing to the role of process technology as a means of assimilating and exploiting external knowledge, the study highlights an important but strongly neglected channel of absorptive capacity.

Third, essay III (see Hoppmann, Huenteler, et al., 2014) demonstrates that deployment policies are endogenous to the technological change they induce. The analysis yields that the German feed-in tariff system for solar PV has gone through a large number of legislative changes, each of which addressed specific issues in the socio-technical system. A key motivation for enacting the Renewable Energy Sources Act (EEG) in 2000 was to raise the financial incentive for installing PV plants, thereby enabling firms to enter the stage of mass production, reducing the costs of PV technology and creating domestic jobs in a promising high-tech industry. However, over time, with increasing PV deployment and falling technology costs, a number of issues emerged that were not foreseen by policy makers. First, the number of PV installations increased much faster than expected, culminating in debates about the costs connected to technology support that should be borne by electricity consumers. Second, costs of PV technology fell at a considerably higher rate than predicted and resulted in windfall profits for both producers and users of PV technology. Third, especially in recent years, increasing deployment of PV has raised concerns about the stability of distribution grids and the longer-term integration of renewable sources into the electricity market. Finally, while initially the German industry performed well, in recent years a strong Chinese industry has emerged that markets its products in Germany, thereby directly profiting from the demand-side subsidies put in place. German policy makers reacted to each of these issues by implementing changes to the design of the feed-in tariff system. These changes were often successful in resolving the immediate bottleneck, e.g., reducing windfall profits, and can be considered crucial when trying to understand the effectiveness and continuity of the German feed-in tariff scheme. At the same time, however, our analysis shows that not only the solution to issues but also the emergence of new ones was closely related to policy interventions. While the policy incentives often successfully resolved prevalent issues, technological change induced by the FIT scheme often led to the emergence of new, unexpected issues that required policy makers to adjust the design of policies. In this sense, technological change served as both an outcome and a driver of policies targeted at inducing technological progress. We argue that the general pattern of the resulting process is similar to what Rosenberg (1969), described as 'compulsive sequences' in the evolution of technical systems. We therefore label our framework 'compulsive policy-making'.

Finally, essay IV (see Hoppmann, Volland, et al., 2014) shows that innovation induced by deployment policies affects the economic viability of complementary technologies. The simulation demonstrates that the economic viability of battery storage improves with the diffusion and cost reductions in residential PV systems. As a result, although fostering investments in storage is generally not the main goal of policy making, deployment policies in the PV sector strongly contribute to raising the profitability of storage, thereby creating incentives for innovation not only in PV. Currently, the literature on deployment policies strongly focuses on evaluating the effects of policy instruments on the diffusion of technologies for which they set direct financial incentives. Our findings suggest that, especially for network and infrastructure technologies, such a perspective may be too narrow as it neglects positive (or negative) side effects of policy measures on complementary technologies. In this sense, the literature on technology and innovation policies could strongly benefit from a closer integration with the broader literature on technological systems to study how policy interventions alter the configurations and links between system components.

PRACTICAL IMPLICATIONS

The findings of this dissertation allow for the derivation of several recommendations for policy makers and corporate managers. First, the results suggest that deployment policies are a very effective means for inducing technological innovation as they provide firms pursuing more mature technologies with the opportunity to benefit from economies of scale and learning by doing. Especially the latter effects are hard to obtain when only drawing on conventional, direct support of R&D. Yet, because firms pursuing more established technologies benefit from deployment policies to a larger extent than those pursuing less mature technologies, policy makers should design deployment policies in a way that reduces the risk of a technological lock-in, e.g., by complementing them with supply-side incentives.

As a second important implication, the results suggest that, while deployment policies are well suited to induce technological innovation, this does not necessarily imply that they generate a competitive advantage for firms located in the country in which the policy is introduced. Foreign firms may benefit from knowledge spillovers, enabled through private investments in R&D and production equipment. Hence, if intended as industry policy, policy makers should foster deployment in a way that considers knowledge spillovers to foreign firms, e.g., by focusing support on industries that more strong rely on tacit knowledge.

Third, it is of critical importance that deployment policies be designed in a way that allows flexible adaptation to unforeseen developments in the technological sphere. The case of the German feed-in tariff system shows that every change in the complex design of legislations can trigger unexpected technology dynamics. As a result, a frequent monitoring of developments and subsequent revisions of policy is a critical ingredient of efficient deployment policies.

Corporate managers of firms that operate in industries affected by deployment policies should closely monitor policy dynamics and drivers as these policies have the potential to significantly disrupt established industry structures. The findings of this thesis demonstrate that policy-induced market growth allows firms to generate revenues and raises the interest of investors in the industry. As a result, deployment policies represent an important means for increasing the financial resources available to firms that can be invested in both production and R&D. Managers who recognize the opportunities and develop marketable products in a timely manner can reap considerable benefits from policy-induced markets. However, as markets grow and product costs in the industry fall, entry for novel technologies may become more and more difficult. Therefore, with the emergence of deployment policies, speed of technology development and production ramp-up becomes critical for start-ups pursuing novel technologies.

While developing the capabilities and technologies for exploitation become critical success factors in the presence of deployment policies, this thesis presents evidence that firms may put too much emphasis on exploitation to the detriment of exploration during time of strong market growth. The findings of this thesis show that in times of strong market growth, opportunity costs for longer-term R&D are particularly high and qualified personnel is limited which induces firms to shift personnel from explorative toward exploitative activities. While this strategy may seem reasonable in the short-term, this thesis presents some evidence that it may be risky from a longer-term perspective, as investments in R&D are important for absorbing firm-external knowledge. As such, during periods of strong market growth, actively managing the trade-off between exploration and exploitation becomes one of the main tasks of managers and plays a critical role for firm survival in the longer run.

ACKNOWLEDGEMENTS

Joern Hoppmann earned his PhD at the Department of Management, Technology, and Economics, of ETH Zurich in 2013. The dissertation was entitled "The Role of Deployment Policies in Fostering Innovation for Clean Energy Technologies – Insights from the Solar Photovoltaic Industry." His dissertation committee consisted of Volker Hoffmann, Stefano Brusoni and Jim Watson.

DECLARATION OF CONFLICTING INTERESTS

The author declares no potential conflicts of interests with respect to the authorship and/or publication of this article.

FUNDING

The author disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: The author acknowledges the financial support of ETH Zurich, the German National Academic Foundation and the Swiss National Science Foundation.

COMMENTARY ON THE RESEARCH PROCESS

In the following, I would like to point out three major lessons that I learned during the endeavor of conducting my PhD. While I doubt these insights will appear revolutionary to more experienced scholars, I hope that they will help future PhD students successfully master the challenges that come with the decision to conduct a PhD.

The PhD as the beginning of a longer learning journey: Arguably, an important goal of the PhD is to make a significant contribution to the extant scientific literature by providing a new lens on empirical phenomena, developing new methodological approaches, and/or building theory. A key learning from my PhD, however, is that a contribution to the literature should be considered an important but by no means the only goal of the PhD. While at the beginning of my PhD, I regarded publishing my thesis and the individual essays as the primary goal, over the course of my work, I increasingly began to see my PhD as a means towards the larger end of learning. At the first glance, the difference between considering a PhD thesis as an outcome or a means to learning might seem rather unimportant. Yet, from my perspective, this distinction has fundamental consequences for how one would approach and measure the ‘success' of one’s work. If indeed the only goal of a PhD is to develop a thesis that can successfully be published in high-ranking management journals, it would seem advisable to focus on a rather narrow subset of theories, methods and empirical phenomena to develop a deep expertise in this area. In this case, simultaneously exploring a larger number of theories and methods would appear rather inefficient as it limits the degree to which each can be brought to a level of excellence that is required in today’s management journals. If, however, one is to see learning as the main goal of the PhD process, exploration of different theories and methods – even those for which one knows with certainty that they are not relevant for the PhD – appears in a very different light. Given the vast amount of existing knowledge in an ever growing number of disciplines, it seems increasingly important to have a broad understanding of different fields to make a strong, longer-term scientific contribution. In this sense – in line with the theory on organizational learning – early investments in exploration may be essential for building a career as a scholar as it allows for the identification of promising longer-term research avenues which make the best use of one’s capabilities and interests. Compared to a professorship, the status of being a PhD student usually offers a higher degree of flexibility and less short-term commitments, which provides leeway for engaging in exploratory activities. Although publishing, of course, is critical for an academic career, seeing learning as the ultimate goal of a PhD has the advantage of making the PhD a more rewarding endeavor as even failures contribute to this end. Based on my experience, I would therefore encourage PhD students – particularly those interested in an academic career – to see the PhD not as the end but the beginning of a longer learning journey, which entails the exploration of different theories and methods, and making mistakes.

The PhD as a collaborative project: A second major insight from my PhD, which is closely related to the first lesson, is the importance of collaboration. In many academic departments, it still seems a common conception that doing a PhD is a challenge that one has to solve individually without relying too much on the help of others. Of course, to warrant being granted the title of a PhD, candidates need to show that they are capable of doing research themselves and that they have made a significant contribution to the field. From my perspective, however, this does not imply that PhD students should avoid talking to others and try to solve all problems on their own. On the contrary, amid the strongly increasing amount and availability of knowledge, it seems unlikely that as a PhD student is able to develop his or her strongest scientific contribution without the critical comments and remarks of others. During my PhD I benefited tremendously from close interactions with a large number of people. I was in the lucky position to do my PhD in a research group at ETH Zurich that puts a very strong emphasis on collaboration, which allowed me to exchange ideas with other researchers on a daily basis. Moreover, I was very privileged to be given the opportunity to participate in a larger number of workshops, conferences and seminars, and spend seven months as a pre-doctoral research fellow at Harvard University. The possibility to discuss my research with colleagues from a large number of different universities and backgrounds was extremely stimulating for me and I am sure that my thesis would have looked quite different if others had not constantly challenged my ideas. Just like companies, researchers can easily get stuck in particular theories or worldviews if they are not questioned from time to time. Just like in business, however, getting stuck in a particular frame can be very risky as sooner or later the research is likely to be challenged by someone with a different perspective, at the latest when submitting it to a journal. To avoid a rude awakening in the publication process, I would therefore recommend that, from the start, PhD students consider their PhD a collaborative project and integrate feedback from others as early and often as they can.

The PhD as an opportunity to solve societal problems: The third and final message I would like to convey to future PhD students is that it pays off to work on a topic of large societal relevance. Social science differs from ‘hard’ science in that the results of the research process can directly be used to shape and alter the object under investigation. For example, while the laws of physics are generally immune against the intervention of the researcher, the findings of an investigation dealing with the effect of firm strategies on performance may directly be employed to subsequently alter the strategy of the firm. Important findings from social science research often find their way back into practice, which implies that today’s research findings are strongly shaped by the outcome of prior research. One might consider the fact that social science is attempting to capture the dynamics of a moving target a fundamental problem for deriving ‘objective’ theoretical laws. Taking a different perspective, however, the ‘living nature’ of social science can also be considered an advantage as it offers the possibility of conducting research that can be directly used to shape and improve the life of human beings. In my PhD I was very lucky to work with researchers who encouraged me to critically reflect on and strive for societal relevance of my research. It is thanks to these colleagues that I ended up studying the solar photovoltaic industry, an industry which bears major potential to solve some of the most pressing societal issues mankind is facing. Discussing the results of my research with policy makers and seeing the findings being included in practical decision making processes has been very rewarding for me. Thus, choosing a research case of direct societal relevance can provide the PhD project with a higher purpose which may serve as a strong motivator during the PhD, especially in phases where one starts to question the value of one’s theoretical or methodological contributions. If one has the choice, I would therefore recommend picking a PhD topic that not only bears the potential of a strong theoretical or methodological contribution but may simultaneously serve society.

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