



Do policy mix characteristics matter for low-carbon innovation? A survey-based exploration of renewable power generation technologies in Germany

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ABSTRACT

Policy mixes may play a crucial role in redirecting and accelerating innovation towards low-carbon solutions, thus addressing a key societal challenge. Towards this end, some argue that the characteristics of such policy mixes matter greatly, yet with little empirical evidence backing up such claims. In this paper we explore this link between policy mix characteristics and low-carbon innovation, using the research case of the transition of the German electricity system towards renewable energy. Our empirical insights are based on an innovation survey administered to German manufacturers of renewable power generation technologies which builds on the Community Innovation Survey. For our purposes we adjusted the survey to better capture companies' perceptions of policy mixes. Employing a bivariate Tobit model we find evidence that companies' perceptions regarding the consistency and credibility of the policy mix are positively associated with their innovation expenditures for renewable energies, and this positive link intensifies when considering the mutual interdependence of these policy mix characteristics. In contrast, neither the comprehensiveness of the instrument mix nor the coherence of policy processes were found to be related to innovation expenditures. Overall, these findings suggest that future research on low-carbon and eco-innovation should pay greater attention to the characteristics of policy mixes, rather than focusing on policy instruments only. Finally, our findings indicate a need to consider how policy may be measured in innovation surveys to generate better informed policy advice regarding the greening of innovation.

1. Introduction

Achieving the ambitious decarbonization targets established by the Paris Agreement at COP21 in December 2015 requires the redirection and acceleration of innovation towards low-carbon solutions. As recognized by the OECD this implies that “*we need to ensure that we are talking about making all innovation green! To do that requires widespread adoption of the right support frameworks combined with clear and credible government commitments so that green considerations are incorporated into innovation policy settings from the outset*” (Guerria, 2016, p. 36). Similarly, the sustainability transitions literature calls for policy mixes which address the various market, structural and transformational system failures that hinder the much-needed decarbonization of the economy (Jacobsson and Bergek, 2011; OECD, 2015; OECD/IEA/NEA/ITF, 2015; Rogge et al., 2017; Rogge and Reichardt, 2016; Weber and Rohrer, 2012). There remain, however, large discrepancies between these acknowledgements of the importance of greening innovation and

the need for policy mixes, and the mainstreaming of such thinking into innovation policy and research.

For such an endeavour, much can be learned from the literature on eco-innovation, which has long recognized the important role of policy in spurring green innovation (Bergek and Berggren, 2014; Díaz-García et al., 2015; Jaffe et al., 2002; OECD, 2011; Rennings, 2000). Building on the notion of “double externalities” that has emerged over the past two decades, both quantitative and qualitative studies have provided important insights into the measurement and determinants of eco-innovation (Bergek and Berggren, 2014; del Río, 2009; Kemp and Pontoglio, 2011; OECD, 2009). One of the key policy insights of this literature is that eco-innovation depends more on the design of a policy instrument than on its type, with environmental stringency standing out as a particularly relevant design feature (Fronzel et al., 2008; Ghisetti and Pontoni, 2015). In addition, it has been acknowledged that eco-innovation benefits from the combination of demand pull and technology push instruments (Costantini et al., 2015; Peters et al., 2012) as well as systemic

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instruments (Cantner et al., 2016; Smits and Kuhlmann, 2004; Taylor, 2008; Wieczorek and Hekkert, 2012). However, broader policy mix aspects and in particular characteristics such as credibility, consistency and comprehensiveness have so far been addressed only rarely, with some notable recent advances using case studies and patent data (Costantini et al., 2017; Reichardt and Rogge, 2016).

Studies utilizing survey data have to the best of our knowledge not yet included such a broader approach to policy mixes in their questionnaire design and analysis, despite the methodological advantage of gathering more detailed policy data alongside other innovation measures. Yet, a recent review of econometric survey analyses shows that regulation is one of the few generally statistically significant determinants of eco-innovation (del Río et al., 2016). Because of limited data availability, however, the econometric models may capture the effect of a particular policy instrument by including a dummy variable only (del Río et al., 2016). In contrast, some specialized eco-innovation surveys have provided more in-depth insights into the link between policy and green innovation, such as through the inclusion of environmental policy stringency as a policy variable (Johnstone, 2007; Kammerer, 2009) or the simultaneous consideration of long-term targets and several climate, energy and innovation policy instruments (Schmidt et al., 2012). In contrast, large-scale innovation surveys, such as the Community Innovation Survey (CIS) conducted within the European Union, tend to cover policy to a limited extent, and often focus narrowly on public support for research and development (R&D), appropriation methods or obstacles to innovation. Similarly, the Oslo Manual, which provides guidelines for innovation surveys, puts little emphasis on the measurement of policy as a determinant of innovation, despite stressing the important policy guidance role of innovation survey data (OECD, 2005).

A notable exception to this apparent neglect of policy in mainstream innovation surveys is a question block on eco-innovation which was introduced as a supplement to the 2008 CIS wave, following suggestions made by the ‘Measuring Eco-Innovation’ (MEI) project (Kemp and Pearson, 2007). Since then, for participating countries such as Germany, Spain, Italy and France, information on eco-innovation and its drivers has been collected and analysed in these large-scale surveys, with (environmental) policy being explicitly included. Using the CIS survey as a key data source has made it possible to better understand the determinants of eco-innovation in general, and the role of policy in particular (Borghesi et al., 2015; Horbach et al., 2013; Rennings and Rammer, 2011). These studies have however not been able to address wider policy mix concerns, which is unlikely to change with the 2014 CIS wave, as the policy-related questions in the revamped eco-innovation block have remained largely unchanged (Rammer et al., 2016). Yet, given the urgency of climate change and other sustainability challenges we argue that the time has come to rethink how best to capture the link between policy and green innovation in innovation surveys.

In this paper, we take a first step in addressing this current shortcoming in mainstream innovation surveys by using the example of the decarbonization of the energy system, in which renewable energies play a key role (Gallagher et al., 2012; Jacobsson and Bergek, 2004; Negro et al., 2012). Given the supplier-dominated innovation pattern of the energy sector we focus on manufacturers of renewable power generation technologies (Pavitt, 1984; Rogge and Hoffmann, 2010). We limit the scope of our explorative study to the German *Energiewende* because of its ambitious targets and rich policy mix as well as its pioneering role in renewable energy innovation (Bruns et al., 2011; Pegels and Lütkenhorst, 2014; Quitzow et al., 2016; Strunz, 2014).

Building on recent qualitative insights into the impact of policy mix characteristics for innovation in the case of offshore wind power (Reichardt and Rogge, 2016) the aim of our paper is to quantitatively explore this link using survey data. In particular, we are interested in answering the research question whether policy mix characteristics indeed matter for innovation, and focus here on the four characteristics proposed by Rogge and Reichardt (2016): consistency, credibility,

comprehensiveness and coherence (the 4Cs). For this, we build on the CIS questionnaire but redesign it to explicitly capture the current policy mix and low-carbon innovation. The resulting unique dataset collected in 2014 allows us to econometrically analyze the link between policy mix characteristics and green innovation, thereby supplementing patent-based evidence presented by Costantini et al. (2017), suggesting a key role of the comprehensiveness and balance of instrument mixes for patenting activity in energy efficiency. While our study concerns Germany, its insights provide research and policy implications which are also relevant to other regions and countries interested in harnessing the low-carbon market opportunities arising from the Paris Agreement, such as China, California, and the UK (Cai and Zhou, 2014; Anadon et al., 2014; Uyarra et al., 2016).

The remainder of the paper is structured as follows. In Section 2 we develop our analytical framework from the literature and derive hypotheses regarding the link between policy mix characteristics and innovation. Section 3 presents the research case of the German *Energiewende*. This is followed by Section 4, which introduces our methodological approach in terms of sampling, survey design, data collection and data analysis. In Section 5 we present our results, which we then discuss in Section 6. We conclude with policy and research implications in Section 7.

2. Analytical framework and hypotheses

Our interdisciplinary framework draws on environmental economics, innovation studies and policy analysis and follows the typical differentiation between firm-external and firm-internal determinants of eco-innovation (del Río, 2009). Regarding firm-external determinants we focus on the influence of a policy mix, thereby extending earlier work which has highlighted the role of environmental regulation and policy design features, such as stringency for eco-innovation (del Río et al., 2016). Here, we are particularly interested in answering the research question whether policy mix characteristics matter for low-carbon innovation. We therefore focus on the abovementioned four characteristics proposed by Rogge and Reichardt (2016), namely consistency, credibility, comprehensiveness and coherence (in short: the 4Cs). Such characteristics describe the nature of policy mixes and have been argued to affect the performance of policy mixes regarding standard assessment criteria, such as effectiveness and efficiency. As distinct bodies of literatures have used these terms quite differently, here we follow the definitions suggested by Rogge and Reichardt (2016) within their interdisciplinary policy mix framework (see Table 1).

First, we distinguish three levels of the *consistency* of the elements of a policy mix (Rogge and Reichardt, 2016). The first level concerns the consistency of the policy strategy and assesses the alignment of policy objectives, such as cost-effective deployment of renewables or the establishment of domestic manufacturing capacity, thereby capturing the extent to which these can be achieved simultaneously without significant trade-offs. Second, the consistency of the instrument mix captures whether instruments reinforce or instead undermine each other (Kern and Howlett, 2009). Third, the overall policy mix consistency captures the consistency of the instrument mix with the policy strategy, implying that they work together in a unidirectional or mutually supportive fashion (Howlett and Rayner, 2013).¹

The literature suggests that a higher degree of consistency makes policy mixes more effective, for example by reducing the costs and risks associated with green R&D, or by increasing demand for environmentally friendly products and technologies. But the literature also recognizes the limits to policy mix consistency, particularly in

¹ The first and third levels of policy mix consistency relates to what the policy design literature refers to as goal ‘coherence’ and ‘congruence’ of goals and instruments (Howlett and Rayner (2013); Kern and Howlett (2009)).

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