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Original Research Paper

Knowledge spillovers from renewable energy technologies: Lessons from patent citations☆

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ABSTRACT

This paper studies the knowledge spillovers generated by renewable energy technologies, unraveling the technological fields that benefit from knowledge developed in storage, solar, wind, marine, hydropower, geothermal, waste and biomass energy technologies. Using citation data of patents in renewable technologies filed at 18 European patent offices over the 1978–2006 period, the analysis examines the importance of knowledge flows within the same specific technological field (intra-technology spillovers), to other technologies in the field of power-generation (inter-technology spillovers), and to technologies unrelated to power-generation (external-technology spillovers). The results show significant differences across various technologies. Overall, patents in wind, storage and solar technologies tend to be more frequently cited than other technologies. While wind technologies mainly find applications within their own field, a large share of innovations in solar energy and storage technologies find applications outside the field of power generation. The paper discusses the implications of these results for policymaking.

1. Introduction

Climate change mitigation will require the increasing development of renewable energy technologies in the power generating sector. In Europe, renewable energy sources, such as solar, wind, geothermal, marine, hydropower, waste and biomass energy, represent about 24% of electricity production against 48% for fossil-fuels[1] (European Energy Agency (EEA), 2012). Increasing the share of electricity produced by renewable sources could thus greatly reduce the levels of greenhouse gas emissions from the power generation sector, currently responsible for about 30% of carbon emissions in Europe. Although over the last few years, renewable energy production costs have shown notable decreases for several renewable technologies,

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[1] The rest being nuclear energy. Renewable energy is mostly hydropower.

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notably onshore wind and solar PV, some other renewable energy alternatives are still too expensive to compete with fossil fuel technologies[2] (International Energy Agency (IEA), 2015). Technological innovation is thus key to lower the costs of renewable energy technologies.

Public policies play an important role in stimulating innovation in this sector, since private firms have too weak incentives to invest in clean technologies (Jaffe et al., 2005). This occurs mainly because the consequence of pollution is not borne by the firm itself but by third parties (the so-called 'environmental externality') and because innovating firms cannot prevent other firms from benefiting from their new knowledge (the 'knowledge externality'). Additional market failures and barriers (e.g. capital market constraints, information asymmetries, national security externalities; see Gillingham and Sweeney (2012), for a review) as well as characteristics inherent to the process of technological change (e.g. knowledge feedbacks, learning externalities, path-dependency, lock-ins; Arthur, 1989; Nelson and Winter, 1982; Rosenberg, 1994) further justify government intervention in renewable energy technological fields. Yet, many questions remain open regarding how such policy support should be designed. Some of the recurrent questions that have emerged within policy circles deal with the issue of which renewable technological field should receive most policy support. Another set of related questions examine whether R&D policies targeted at renewable energy should encourage more specific or diverse technological trajectories. Parts of the answers require a better understanding of how various pieces of knowledge are combined to enable the development of new technologies and a more careful investigation of how specific knowledge flows *within* or *across* technological fields. Consider, for instance, wind energy: if inventors in wind energy technologies mostly learn from prior art within the same technological field, these intra-technology spillovers will tend to reinforce the existing technological trajectory, so that R&D subsidies specifically targeted at wind energy will be particularly effective at encouraging further developments in this technological field. If instead technological developments in wind energy are driven by knowledge from various technological domains, then more generic policy measures targeted at developing inter-technology spillovers may be more beneficial.

To provide some first answers to these questions, this study aims to present evidence on the extent and the direction of knowledge spillovers generated by renewable energy technologies. Our main research questions are: (1) which renewable energy technological fields generate the most knowledge spillovers? and (2) where do knowledge spillovers generated by renewable technological fields flow to? To address this second research question, we make a distinction between intra-technology knowledge spillovers (knowledge flows within the same field of renewable energy technology), inter-technology spillovers (knowledge flows to other power generation technologies) and external technology spillovers (knowledge flows to technologies outside the power generation field[3]). Our empirical analysis uses citations of patents in eight renewable energy technologies filed at 18 European patent offices over the 1978–2006 period. Results from negative binomial estimations show that wind, storage and solar patents tend to be the most frequently cited patents, suggesting that these fields are particularly important and valuable for society. Regarding the direction of knowledge spillovers, we find significant differences across the various technological fields. While wind technologies mainly find applications within their own technological field, a large share of innovations in solar energy and storage technological fields find applications outside the field of power generation. We provide a detailed description of the technological fields that benefit the most from knowledge in renewable energy and discuss the implications of our analysis for policymaking. The study is organized as follows. Section 2 describes the literature on knowledge spillovers, in particular related to energy. Section 3 discusses the patent data used in the analysis and the empirical methodology. Section 4 presents the results on knowledge spillovers. Section 5 discusses the implications for policies. Section 6 concludes.

2. Knowledge spillovers and energy patents

The notion that technological innovation is the result of the combination of existing components is deeply rooted in the literature on the history of technological change (Usher, 1954). Nelson and Winter (1982) describe innovation as consisting "to a substantial extent of a recombination of conceptual and physical materials that were previously in existence" (1982, p.130) and emphasize the role that firms play in combining technical, organizational and market knowledge. The inherent combinatorial characteristic of innovation has led scholars to focus on the question of how new technologies build on prior art and on how inventors combine and transfer knowledge across technological domains. Since knowledge is a public good, part of an inventor's original idea necessarily spills over to other firms, other sectors and other technological fields, generating positive externalities (the so-called 'knowledge spillovers') for the economy.

Previous work on knowledge spillovers has exploited the comprehensive information provided by patent data to examine how knowledge flows from one inventor to the other. The analysis of R&D manager surveys by Jaffe et al. (2000) shows that patent citations provide a reasonably good indication of communication between inventors – a 'learning trail' – in the knowledge transfer process. As a result, a large body of literature has used patent citations to proxy the importance of

[2] According to International Energy Agency (IEA) (2015), indicative global average onshore wind generation costs for new plants fell in the period 2010–2015 by an estimated 30% on average while that for new utility-scale solar PV declined by two-thirds, and additional declines are forecasted for the next five-year period. However, technologies such as offshore wind, solar thermal electricity and some bioenergy are still at the beginning of their learning curve.

[3] Strictly speaking, we define external citations as citations to technological fields that are not included in our list of renewable and fossil fuel technological fields shown in Appendix A. The list covers a lion share of power generation and electricity storage fields. All the other technologies in the field of energy, e.g. energy transmission, are allocated to the external technology field.