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Directing technical change from fossil-fuel to renewable energy innovation: An application using firm-level patent data ☆

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ABSTRACT

In this paper we provide an analysis of directed technical change in the sector of electricity generation. We rely on patent data in fossil-fuel (FF) and renewable energy (REN) technologies for 5471 European firms over the 1978–2006 period. The novelty of our approach is in the focus on firm's heterogeneity in driving technological change. We make a distinction between small specialized firms, which innovate in only one type of technology, and large mixed firms, which innovate in both technologies, to analyse how REN patents can replace FF ones at the sector level both through a shift in innovation activities within existing firms and through firms' entry and exit. We use zero-inflated count data estimation techniques to identify the factors that affect specialized versus mixed firms' patenting behaviour both at the intensive (i.e., levels of innovation) and extensive (i.e., technological entry) margins. We further investigate the implications of our firm-level estimations for reducing the gap between REN and FF innovation at the aggregate level. We establish two key findings: (1) a decrease in the FF-REN technology gap mainly comes about through technological entry of specialized REN firms following an increase in REN market size; (2) increases in FF prices, FF market size, and FF knowledge stocks all increase the technology gap by increasing mixed firms FF innovation rates. An important implication of our results is that policies aimed at increasing REN innovation should focus on helping small firms to start and sustain innovation in the long-run.

Introduction

Currently, approximately 70% of the world's electricity is produced from highly carbon-intensive fossil fuels, namely, coal, oil, and gas. Some countries, such as Australia, China, India, and Poland, produce between 70% and 95% of their electricity through the combustion of coal only (IEA, 2010). This large reliance on fossil fuels explains why the sector of electricity generation is by far the largest producer of carbon emissions. Electricity production generates 41% of worldwide carbon emissions – twice the share of the transport sector – and emissions are expected to increase sharply in the future due to

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increasing electricity demand, notably from developing countries. In light of this, achieving substantial emission reductions will call for de-carbonizing the electricity generation sector and, thus, moving away from the dominance of fossil-fuel (FF) technologies.

Renewable (REN) energy, such as solar, wind, and renewable combustibles, can provide a clean alternative to electricity production. Yet, despite recent developments, renewable energy represents only 18% of the world's electricity. Accelerating technological innovation in renewable technologies can contribute to lowering the cost of renewables so that they can compete on a level playing field with conventional FF energy sources (IEA, 2010). Specifically, directing technological innovation away from traditional fossil fuel technologies toward renewable ones might be particularly effective in this regard.

In this paper, we provide an analysis of directed technical change in the electricity generation sector using patent data in FF and REN energy technologies for 5471 European firms over the 1978–2006 period. Several papers have looked at the factors that affect the rate of innovation either in FF or REN electricity generation (Hascic et al., 2009; Lanzi et al., 2011; Johnstone et al., 2010) but not how these factors can induce a shift away from FF toward REN innovation at the firm and sector levels. The only empirical study that looks at how policies can redirect innovation away from dirty technologies is Aghion et al. (2015), but their focus is on the automobile sector. Our approach is innovative, compared to prior research, through its focus on firms' heterogeneity in driving technological transitions. In particular, we make a distinction between 'specialized' firms, which innovated in only one technology over the 1978–2006 period, and 'mixed' firms, which innovated in both REN and FF during the period.

There are several reasons why this distinction is conceptually important. First, it is in line with stylized facts in the economic literature on innovation and economic growth that provides evidence of heterogeneity in firms' innovation behaviour and that highlights differences between small occasional innovators and large persistent ones (Acemoglu and Cao, 2010; Akcigit and Kerr, 2010; Arque-Castells and Mohnen, 2012). The presence of sunk costs to enter R&D explains why small firms that specialize in a single technology may coexist with large firms with a broad research portfolio. As part of our analysis, we provide descriptive statistics that illustrate systematic differences between specialized and mixed firms in electricity generation technologies. Compared to mixed firms, specialized firms are younger and smaller (in terms of turnover, assets, and employees) and innovate more incidentally.

Second, firm heterogeneity is important to understanding how new technologies can replace older ones at the industry level through both the reallocation of innovation activities within existing firms and through firms' technology entry and exit dynamics, which is akin to Schumpeter's notion of 'creative destruction'. In contrast to the standard theory of firm behaviour, the process of 'creative destruction' relies on heterogeneity among producers to explain how firm dynamics, through entry, exit, expansion, and contraction, continuously introduce new products, markets, and technologies to replace existing ones in the economy. In the context of energy systems, the role of firm entry into REN technologies in transforming the energy sector has been discussed by Jacobsson and Bergek (2004). In the same vein, our empirical analysis emphasizes the role of new technological entrants that specialize in REN innovation. We find that, in recent years, the reduction in the aggregate technology gap between FF and REN patenting activities in the electricity generation sector has been induced mainly by increased entry of specialized firms in REN innovation and the simultaneous exit of specialized FF firms. However, innovation by mixed firms has remained largely concentrated in FF technologies with only a moderate shift toward REN technologies.

Our econometric analysis uses zero-inflated count models to investigate the factors that affect heterogeneous firms' decisions to patent in REN and/or FF innovation, both at the extensive margin (i.e., whether to conduct any innovation at all) and at the intensive margin (i.e., the rate of innovation conditional on a positive innovation decision). We further investigate the implications of our estimates on this sample of European firms for reducing the gap between REN and FF innovation at the aggregate level and establish two key findings: (1) a decrease in the FF-REN technology gap mainly occurs through specialized firm REN innovation entry, following an increase in REN market size; (2) increases in FF prices, FF market size, and FF knowledge stocks all increase the technology gap by increasing mixed firms' innovation rates. We also find that the highly incidental nature of innovation by specialized REN firms suggests that there is a great deal of underutilized innovation potential in the economy. Hence, an important implication of these results is that policies aimed at increasing REN innovation should focus on helping small firms to start and sustain innovation in the long run.

The rest of this paper is organized as follows. The section "Literature review and conceptual framework" presents a discussion of the related literature, underlying theory, and the hypotheses that we will test in our empirical section. The section "Trends in patenting and innovation entry dynamics" provides some descriptive trends of innovation activities by heterogeneous firms in REN and FF electricity-generation technologies. The section "Data and methodology" presents the data sources and empirical strategy. The section "Estimation results" contains the main results and robustness analysis. The section "Conclusion" concludes.

Literature review and conceptual framework

Background literature

There is an extensive literature in environmental economics on the factors that affect clean innovation. The starting point of this literature is the induced innovation hypothesis of Hicks (1932), which posits that inventions are triggered by changes in the relative prices of production factors. In line with Hicks' idea, Popp (2002) finds strong evidence for a positive effect of