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Invention in energy technologies: Comparing energy efficiency and renewable energy inventions at the firm level ☆

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HIGHLIGHTS

- Patent panel data on energy technologies for a panel of firms.
- Dynamic count data panel analysis using GMM and pre-sample mean estimation.
- Relationship between energy and non-energy technologies within firms.
- Relationship between different energy technologies within firms.

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ABSTRACT

Many countries, especially in Europe, have ambitious goals to transform their national energy systems towards renewable energies. Technological change in both renewable production and efficient use of energy can help us to make these targets come true. Using a panel of German firms linked to the PATSTAT patent data, we study inventions in both types of energy technologies and investigate the role prior inventions as technology-push factors play for both types of technologies. In addition and more importantly, we study whether previous inventions in non-energy technologies also stimulate technical change in energy technologies and whether this effect differs between energy conservation and renewable energy technologies.

1. Introduction

In light of increasing prices for energy and increasing problems of climate change due to the extensive use of fossil fuels, many countries pursue a transition of their national energy systems towards renewable energies. In these countries—for instance Denmark, Spain, and recently Germany—invention and innovation in renewable energy technologies can help achieve these targets at lower costs. In addition, also innovation in energy efficiency is central to the realisation of the energy transition. Technological change in this area has been identified as the central driver to reduce aggregate energy intensity (Voigt et al., 2014). Moreover, in countries where the share of total energy consumption due to energy-intensive manufacturing increased in the last years—as for instance in Germany or Taiwan (Voigt et al., 2014)—technological change is even more important to economise energy costs.

This paper takes a deeper look into technological change at the level of inventors. In particular, it investigates the role of path dependency as a technology-push factor and key driver of energy inventions. We expect the impact of path dependency in the same technology on related inventions to differ between energy efficiency and renewable energy inventions. Our central hypothesis is that path dependency in the same technology is more important for renewable energy technologies and less important for energy efficiency technologies. Regarding the latter, however, firms are expected to be less specialised in developing such technologies so the history of technical progress in other non-energy technologies is expected to be another key driver of inventions. This is because energy efficiency technologies can be seen as a valuable component in the technological portfolio of firms developing and manufacturing energy-using product. Invention of non-energy technologies creates incentives and technological opportunities to

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develop energy efficiency technologies, especially in the presence of high energy prices and regulation. Conversely, providers of renewable energy equipment (e.g. solar panel or wind turbine manufacturers) are expected to be rather specialised in developing such technologies. We therefore do not expect a positive relationship between renewable energy technologies and non-energy technologies to exist. However, for the other inventors active in renewable energy technologies, for instance firms in the chemical sectors, such a positive relationship could exist so that the overall effect is unclear.

Results are drawn from longitudinal data of a sample of 376 German companies active in energy research and development (hereinafter R&D). These firms have been identified on the base of patents granted by the European Patent Office (EPO) and originate from a representative firm survey panel—the Mannheim Innovation Panel (MIP)—covering more than 50,000 companies in all sectors from 1992 on. In contrast to previous research, we study invention in energy technologies within a broad range of sectors including manufacturing and service sectors. This is of central importance as the overwhelming number of energy conservation patent holders come from manufacturing sectors, especially from the sectors of manufacturing of computers and electrical equipment as well as the automotive sectors. Conversely, the sector contributing most to the overall number of renewable energy patents is the scientific research and development sector. By jointly studying manufacturing and service sectors, our study allows us to draw a more comprehensive picture of invention activities in energy technologies.

The results reveal some important differences between energy conservation and renewable energy technologies. For the former, there is a relatively small amount of path dependency observed compared to renewable energy inventions. However, inventions in non-energy technologies at the firm level are significantly associated with technical change in energy conservation technologies. Put it otherwise, firms with a larger amount of technological knowledge (accounted for by non-energy patents) produce at the same time more energy efficiency patents and not less. For renewable energy technologies, this relationship is not observed. Hence, there are quite different technology-push factors at work that stimulate the development of energy technologies. Understanding in much more detail how energy inventions are related to non-energy inventions at the firm level is crucial for policy makers to set properly designed incentives for technological development.

The remainder of the paper is organised as follows. Section 3 describes the underlying data sources of this paper and presents descriptive statistics on the history of renewable energy and energy conservation technologies. The empirical model is presented in Section 4 followed by a discussion of our results in Section 5. Section 6 concludes.

2. Previous research and research questions

Economic research studying the pace and direction of technological innovations typically distinguishes between two factors influencing innovation opportunities and incentives—technology-push and demand-pull factors.[1] The importance of demand-pull factors for inventions can be traced back to the work of Schmookler (1966) and has been stressed by researchers studying innovation related to energy technologies. In this sense, previous research typically relies on the demand factor energy prices and the related concept of price-induced inventions based on the work of Hicks (1932). Following Hicks (1932), a change in the relative price of an input factor (such as energy) stimulates innovation to find production technologies that require less inputs of this factor. Empirical evidence on energy price-induced technical change is documented by Lichtenberger (1986), Newell et al. (1999), Popp (2002), or more recently Crabb and Johnson (2010), amongst others. Most recently Aghion et al. (2015) find that firms in the automobile sector invent more in electric or hybrid engine technologies in the presence of higher fuel prices. Also the adoption of innovations has been identified to follow changes in the price of energy (Rose and Joskow, 1990; Jaffe and Stavins, 1995; Linn, 2008, among others) and thus creates demand for inventions.

In addition to energy prices, regulation is identified as a key driver of energy technologies, see Newell et al. (1999) amongst many others.[2] For regulation-driven[3] energy innovation, especially for renewable energy technologies, much less empirical evidence exists. In the case of renewable energy technologies, Johnstone et al. (2010, p. 146) conclude that “In general, policy, rather than prices, appears to be the main driver of innovation in these technologies.” Nemet (2009) adds to the discussion that governmental policy (or demand-pull) was not the driving force of invention of the most important wind power technologies (measured with highly cited patents). The most important reason he gives is that rapid technical improvement in wind power led to a dominant design lowering the market opportunities for more important, i.e. radical, inventions in this technology. Glachant and Dechezleprêtre (2014) show that also foreign environmental demand-pull policy plays a significant but much smaller role than domestic policy in stimulating domestic wind power inventions. Noailly and Batrakova (2010) provide case study evidence onthe role governmental policy plays in stimulating inventions for heating insulation, energy-efficient boilers and lighting. Most recently, Calel and Dechezleprêtre (2015) document low-carbon inventions (including alternative renewable patents) induced by the European Emission Trading Scheme (EU ETS).

So far, little attention has been paid to technology-push factors by the literature on energy inventions. One central technology-push factor is the history of technical change itself. In this context, Dosi (1982, p. 1534) emphasises that “[…] each body of knowledge specific of particular technologies (each ‘paradigm’) determines the notional opportunities of future technical advance […].” Besides the inducement effect of changes in energy prices, Aghion et al. (2015) consider also the role of historical inventions by firms in the automotive industry. They find that firms' past invention activities are a central determinant of current inventions in either “clean”, i.e. electric or hybrid, or “dirty” (combustion engine) technologies. This path dependency phenomenon holds for both clean and dirty technologies where there is so far a higher stock of dirty inventions. Aghion et al. (2015) conclude that a considerable increase (40%) in energy prices is needed for the clean technology stock to overtake the dirty one (after 15 years) and to overcome a lock-in in dirty technologies. Regarding the identified path

[1] The interested reader is referred to Mowery and Rosenberg (1979) for an intensive discussion on demand-pull vs. technology-push as drivers of innovation.

[2] Most of the regulation-induced literature deals rather with environmental innovation in general, see Jaffe et al. (2002) and Popp et al. (2010) for comprehensive reviews of this literature. Policy-stimulated demand for renewable energy technologies (feed-in-tariffs), however, is not found to be a significant driver of related innovation; see Braun et al. (2010) and especially Böhringer et al. (2014) for German evidence.

[3] Note that there is also literature analysing the effect of deregulation on energy R&D. Nakada (2005) sets up a theoretical model and arrives at the conclusion that deregulation of an energy market can foster innovation if the market structure is concentrated before the deregulation. Conversely, Jamasb and Pollitt (2011) find that liberalisation in the United Kingdom's electricity sector has reduced its R&D spending but, on the other hand, led to more patents for renewable and non-nuclear energy technologies in the time after the liberalisation. A more recent contribution by Nesta et al. (2014) finds that deregulation complements environmental policies in stimulating innovation in renewable energy technologies.