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Viewpoint

Technological innovation in the energy sector: R&D, deployment, and learning-by-doing

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Abstract

Technological innovation is fundamental for rendering the energy economy cleaner and more efficient with concomitant economic, developmental, and environmental benefits. This paper discusses aspects of R&D and 'learning-by-doing,' the main contributors to technological change that are complementary yet inter-linked. The relationship between the level of national energy R&D investments and changes in the trajectory of the country's energy system is complex; targeted efforts to promote deployment of new energy technologies play a major role in translating the results of R&D activities to changes in the energy system. Learning-by-doing is an important element of deployment, but it remains largely poorly understood. Hence this phenomenon needs to be 'unpacked' and its various aspects analyzed in detail, so as to allow better design of early deployment efforts to enhance learning gains. This paper highlights how public R&D and deployment efforts must work in tandem to expand the portfolio, and realize the potential, of new and improved energy technologies.

Keywords: Clean energy transition; Energy research and development; Learning-by-doing

1. Introduction

The development and deployment of new and improved energy technologies have been, and will continue to be, central to the transition towards cleaner and more efficient forms of energy production and consumption. New technologies enable shifts in the trajectory of the energy sector in many different ways, allowing it to deliver improved services, to become more efficient, and to respond to environmental concerns such as local air pollution and global climate change. For example, stabilizing 'greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system,' as required by the Framework Convention on Climate Change (UNFCCC, 1992), will require a significant reorientation of national energy trajectories. Yet realizing the potential benefits of technological innovation is often not straightforward—there is 'many a slip 'twixt the cup and the lip' that inhibits the translation of investments directed towards technological change into a positive evolution in the performance of the energy sector. This paper seeks to highlight and discuss some aspects of the relationships between such investments and resulting changes in the energy economy. In particular, this article stresses the role of targeted deployment efforts in overcoming barriers to the widespread adoption of new and improved energy technologies, and the specific role of 'learning-by-doing' in effective deployment strategies.

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2. Components of technical change

Various steps can be discerned in the 'life' of a technology, from invention through innovation, commercialization, diffusion, saturation, and senescence (the last two stages combined can be referred to as 'maturation'; see, for example, Grübler, 1998; Grübler et al., 1999). Still, only two main components of technical change exist: R&D and learning-by-doing (see, e.g., Carraro et al., 2003). These occur at different stages of technological evolution. R&D—or RD&D: research, development and demonstration—mostly takes place at the early stage of technical development, preceding the commercial use of a nascent technology.[1] This phase might never be followed by commercial deployment. Learning-by-doing, or 'learning' in short, is the phenomenon arising from the moment the new technology is first practically used, and lasts all through the maturation stage. Learning can lead to cost reductions, greater proficiency in technology operation (that could lead, for example, to safety improvements), as well as institutional transformations necessary to support the introduction and diffusion of new technologies and allow them to enter the realm of widespread use. Learning rates are highest in the initial stages of technology deployment; the corresponding improvements often play a key role in the large-scale uptake of new energy technologies (van der Zwaan and Seebregts, 2004).

Both elements—R&D and learning—play important roles in the process of technological change. No major changes can occur in existing technologies, if explicit effort is not made through research and development, however uncertain the outcome of such endeavors may be. But R&D spending that successfully leads to a new technological concept without the acquisition of experience through deployment that involves learning will make the technology that much harder to implement on a wide scale.

The relationship between investments directed towards technological change and the energy economy is complex. In particular, as is pointed out in the next section, there are significant variations in national trends between historic levels of public R&D expenditures and improvements in the energy intensity or carbon factor (EI and CF, respectively) of a given economy. Clearly, energy R&D (ER&D) does not automatically lead to a predefined level of technological change in the real world. Even if a new technology has been conceived, its deployment and widespread use is not a given fact. Not only are incentives needed to deploy, but also the capacity to learn through deployment. If no such capacity exists to learn, then it is that much harder to surmount the initial higher costs as well as institutional barriers that may stand in the way of the commercial deployment of the new technology.

[1]We use the term R&D in this paper as also including demonstration. The same is true of the public ER&D budget data presented in this paper.

3. R&D necessary but not sufficient by itself

In recent years, there has been much concern about trends in public-sector ER&D budgets, especially in the context of the challenges posed by climate change, since addressing these almost certainly requires significant innovation in the energy sector (see, for example, PCAST, 1997; Dooley, 1998; Morgan and Tierney, 1998; Margolis and Kammen, 1999). The role of R&D in changing the trajectory of the energy economy is unquestionably important—new technologies have played a central role in the evolution of the energy sector over the last century, through improvements in resource exploration and extraction techniques, as well as in methods of energy conversion and utilization. Private ER&D is critical for realizing changes in the energy system, but in many cases—for example in areas related to the production or preservation of public goods and services—government involvement in ER&D may often be justified and desirable, and indeed play a key role (PCAST, 1997).

Such public ER&D spending has often led to the development of innovative technologies that have had a significant impact on the energy sector (see, for example, NRC 2001). Yet an examination of past trends in some major industrialized countries indicates that public ER&D spending across these countries does not display clear correlation with changes in relevant indicators such as national energy intensity (EI, the level of energy consumption per unit of GDP) or carbon factor (CF, the amount of carbon emissions per unit of energy consumption).

Table 1 shows the average annual changes in the EI (i.e., $\mathrm{dEI}/\mathrm{d}t$) and CF (i.e., $\mathrm{dCF}/\mathrm{d}t$) of selected industrialized economies over the period 1975–1999, as well as the average annual public ER&D budgets and average public ER&D intensity (ER&DI), i.e., public ER&D expenditures per unit of GDP, over this interval.[2] While the time lag between ER&D spending and resulting changes in the energy sector may be substantial, over a 25-year period one would expect to see some correlation between levels of ER&DI (or ER&D budgets) and changes in EI and CF.[3] The data in

[2]By scaling ER&D efforts in relation to the total economic activity in a given country, the ER&DI allows for a cross-country comparison of such efforts. But at the same time, an examination of total ER&D budgets is also helpful, since these give an idea of the overall size of public activities in this area.

[3]Some elements of ER&D programs could affect the CF but not the EI. For example, fission R&D that has contributed to the replacement