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From fossil fuels to renewables: The role of electricity storage☆

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ABSTRACT

Electricity storage represents a solution to curb carbon emissions by enabling more use of intermittent renewable energy. Our goal is to empirically analyze the determinants of innovation in electricity storage and its role in fostering technological innovations in renewable and conventional electricity generation. Using a global firm-level data set of electricity patents from 1963 to 2011, we find that better electricity storage promotes innovation not only in renewable energy but also in conventional technologies. Specifically, our estimates show that an additional storage patent increases the probability to apply for patents in renewable energy and efficiency-improving fossil fuel technologies two years from now by 1.09% and 0.65%, respectively. This implies that improved electricity storage technologies can boost the energy efficiency of conventional, fossil fuel-fired power plants as well as increase the use of renewable electricity. Thus, the ability of electricity storage to curb carbon emissions depends on: the competitiveness of renewable energy against conventional electricity generation, and conventional power generation mix as storage increases fossil-fuel efficiency and reduces ramping costs.

1. Introduction

Concerns over climate change have led society to seek alternatives to reduce carbon emissions. To that end, many call for a shift in energy production from fossil fuels toward renewables. Although renewable energy can provide a clean source

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of electricity, fossil fuels still account for the vast majority of the world's electricity generation.[1] As a consequence, electricity generation is currently the single largest carbon emitter globally, and with energy demands continuing to grow rapidly, innovation in the electricity sector is an important channel for curbing carbon emissions. Although innovation has already resulted in new and improved renewable technologies, electricity storage is often considered to be a key innovation challenge for meeting renewable goals because large-scale storage solutions can boost the use of intermittent renewable energy in the grid mix.

Our main goal is to study the role of electricity storage for innovation in the electricity sector. Specifically, we ask two main questions. First, how do better storage technologies affect innovation in renewable and conventional electricity generation? Second, how does innovation in electricity generation affect technological advancements in storage? To answer these questions, we develop testable hypotheses based on a directed technological change framework, and then, we test these hypotheses using a global firm-level database of patents related to electricity generation and storage from 1963 to 2011.

The most widely used form of electricity storage is pumped hydro, which accounts for over 90% of the current global storage capacity and has been used commercially since the 1890s. However, current innovation efforts mainly target other technologies, including batteries or compressed air storage, because the potential to expand the use of traditional pumped-hydro storage is limited by the availability of suitable sites.[2] Many of these initiatives seek a breakthrough in batteries, but governments and private companies also direct innovation efforts to a multitude of other possible solutions.[3] These include ways to use cheap and easily available materials, including air and water, as the storage media (e.g., compressed air and flywheels), hydrogen-based technologies, and electrical and thermal storage.

We start by developing testable hypotheses that builds on the directed technological change framework used by Acemoglu et al. (2012) and Aghion et al. (2016). Specifically, we consider three types of innovation: innovation in renewable electricity generation, innovation in conventional electricity generation, and innovation in electricity storage. Innovation in electricity generation results in cost savings, whereas innovation in storage improves the elasticity of substitution between renewable and conventional electricity production. Our main hypothesis is that better storage technologies promote innovation in both renewable and conventional electricity when the two production processes are substitutes.

To conduct our empirical analysis, we first build a global firm-level data set of electricity patents. We focus on Triadic patents, which are patents filed in all of the three major patent offices: the European Patent Office (EPO), the US Patent and Trademark Office (USPTO), and the Japanese Patent Office (JPO). In total, we identify 19,232 unique Triadic patent applications for electricity storage, 154,041 for conventional technologies, and 178,841 for renewable technologies. In addition to the patent data, we use data on energy prices and macroeconomic variables. Altogether, our data set covers 13,877 firms, across 79 countries, for a period from 1963 to 2011. Using this data set, we estimate a dynamic firm-level innovation model that allows current innovation in each technology to depend on past innovations in the three technologies.

Our empirical results show that the development of new storage technologies promotes innovations in both renewable and efficiency-improving conventional technologies. Specifically, an additional storage patent at the average firm two years ago, raises the probability to apply for patents today by 1.09% for renewable energy patents and 0.65% for efficiency-improving fossil fuel patents. Furthermore, after we disaggregate patents into narrower categories, we find that an additional storage patent leads to a 1.15% higher probability to apply for a patent in intermittent renewable technologies, while we find no evidence for a statistically significant effect of storage on peak-power fossil fuel technologies. Hence, electricity storage not only benefits renewables by mitigating the intermittency problem, but also encourages the development of more efficient fossil-fuel technologies and affects the energy mix in conventional technologies. Therefore, electricity storage can enable full exploitation of the energy potential in intermittent renewables, as producers can simply produce as much electricity as the sun and the wind offer at all times, store it, and dispatch it to the grid when needed. In addition, storage technologies can create new arbitrage possibilities for conventional electricity producers, because storage enables them to produce at a fairly constant rate, thereby minimizing ramping and other costs, to store the electricity, and to dispatch it during peak periods. Although it has been widely argued that electricity storage is a key solution to reducing carbon emissions in the electricity sector, this is the first paper to provide evidence that better storage not only improves the potential for renewable technologies but also boosts the efficiency of the entire electricity sector. These results imply that while storage can strengthen the potential for reducing carbon emissions from the electricity sector, the mere existence of new storage technologies does not guarantee lower emissions. The overall effect on carbon emissions also depends on other factors, such as new installed storage capacity and the relative competitiveness of low-carbon energy sources.

In addition, our empirical analysis explores the incentives to innovate in electricity storage. First, our results show the existence of a positive feedback effect between innovation in storage and in renewable generation, as more past innovation in renewable technologies leads to more innovation in storage. In contrast, we find no evidence for such feedback between

[1] According to the International Energy Agency, in 2013, 67.2% of world electricity production came from conventional fossil fuel-powered plants. Hydroelectric plants provided 16.6%, nuclear plants 10.6%, biofuels and waste 2.0%, and the rest came from geothermal, solar, wind, and other sources (IEA, 2015).

[2] Fig. B.1 shows global installed storage capacity by technology from 1950 onward.

[3] Indeed, the media describe the occurrence of a technology race in electricity storage, with scientists searching for game-changing solutions to the challenge of storing electricity. See, for example, "How energy storage can change everything" by Daniel Burrus (http://www.huffingtonpost.com/daniel-burrus/how-energy-storage-can-ch_b_8010258.html) or "Innovation sputters in battle against climate change" by Eduardo Porter (http://www.nytimes.com/2015/07/22/business/energy-environment/innovation-to-stanch-climate-change-sputters.html).