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Teaching an old dog new tricks: Firm learning from environmental regulation

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ABSTRACT

We examine a new mechanism by which environmental regulation can increase efficiency: intra-firm knowledge spillovers due to environmental regulation. County-level non-attainment of the National Ambient Air Quality Standards creates spatial variation in the degree of regulatory stringency, as states impose stronger environmental regulation in non-attainment counties. We use this spatial variation to examine how the efficiency of electricity generators responds to increases in regulation. We show that, in response to increased regulatory stringency, electricity generators find technical efficiency enhancements and then transfer these enhancements to other units within their fleet. We find that a change in regulatory stringency translates to within-firm spillovers of 3–4%, and that these gains occur at least 3 years after the increase in regulatory stringency.

1. Introduction

Innovation is the creation of knowledge. Learning is the transfer of knowledge across people or groups. Both innovation and learning are fundamental to economic growth and are thus of great importance to firm outcomes. Consequently, much empirical work has been dedicated to observing and measuring firm innovation.[1] However, it is difficult to empirically observe learning at the firm level.

To measure firm learning one must first identify learning networks: groups that share knowledge. Additionally, empirical estimation of the effect of learning requires some event that forces firms to create new knowledge and then allows these firms to share this knowledge through networks. The electric power industry, in which firm ownership connects multiple distinct power plants, and changes in environmental regulation, which require plants to adapt and potentially spark innovation, provide a framework in which we may measure how firms learn.

In this paper, we examine firm learning in response to regulation through changes in technical efficiency in the electric power industry. Using county level variation in the stringency of environmental regulation of power plants created by the National Ambient Air Quality Standards (NAAQS) under the Clean Air Acts, we examine both how firms respond to an increase in regulation at one plant and how efficiency enhancing knowledge is transferred within the firm. We concentrate our analysis on the electricity generation industry for a number of reasons. First, power plants are large stationary sources of emissions and are major targets of environmental regulation. According to the National Emissions Inventory in 2014, the electricity sector is responsible for 64% of sulfur dioxide emissions and 14% of nitrogen oxide emissions. Second, electricity generation provides us with an objective measure of technical efficiency, the heat rate of a generator. The heat rate is the amount of fuel consumed

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[1] See Mairesse and Mohnen (2002) for a detailed discussion of measurement of innovation.

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to produce a single unit of electricity. Both environmental regulation and operational characteristics of the plant affect the heat rate (Linn et al., 2013), making it an ideal dependent variable for our empirical analysis. Third, the Environmental Protection Agency (EPA) and the Energy Information Association (EIA) collect extensive, generator level data on the industry, allowing for a panel of data spanning more than 40 years.

The NAAQS provide a natural experiment in which to study the effect of environmental regulation. The NAAQS consist of a series of county-level air quality standards for various pollutants in the United States. Counties that fail to meet the annual air quality standard for a given pollutant are said to be in "non-attainment" of that standard for the following year, while counties with emissions below the standard are in "attainment". Under the Clean Air Act Amendments (CAAAs), states must implement more stringent environmental regulation for non-attainment counties in order to reduce their pollution concentrations, though these regulations may be loosened once counties come into attainment with the NAAQS. Power plants in non-attainment counties therefore face more stringent environmental regulation than plants in attainment counties, creating both temporal and spatial variation in regulatory stringency. We exploit this variation to identify the effect of environmental regulation on firm learning.

While our results vary by fuel type, we find that when non-attainment of a pollutant is likely to cause additional regulation of power plants, this non-attainment has positive effects on efficiency. For example, coal plants experience an average efficiency gain of 4.61% in response to non-attainment of the 1-hour ozone standard. We also find evidence that plants in non-attainment counties transfer these efficiency gains to other plants within the learning network (i.e. firm) that are not subject to increased environmental regulations. These coal plants in attainment counties with connections to coal plants in non-attainment counties receive positive average spillovers of 3.80%. Semi-parametric estimates of these spillovers reveals that spillovers generally begin after 3 years.

These efficiency gains appear to come through process innovation. We identify four pathways through which the efficiency of generators in attainment and non-attainment counties within the firm may change in response increased regulatory stringency and directly examine two of these pathways. Our conclusion from these direct tests is that process innovation is the primary contributor to generators' increase in efficiency.

The first section below describes the variation in environmental regulation that we use to identify regulatory spillovers and the current literature about firm responses to environmental regulation. as well as how the environmental regulations we focus on are likely to affect a firm. Section 3 discusses the data we use to examine firm learning and Section 4 discusses our identification strategy. We then discuss our results in Section 5 and explore potential mechanisms that contribute to the results. Next we present our primary results and tests of alternative explanations. Finally, Section 6 concludes.

2. Regulation and firm learning

Over the last half century the United States has substantially increased the federal regulatory authority over environmental quality. Among the most significant laws in this area are the Clean Air Acts of 1963 and subsequent amendments in 1970, 1977, and 1990. The 1970 Clean Air Act Amendments established the NAAQS which set a minimum level of air quality that must be achieved in each county in the United States. In counties that do not meet these air quality standards, states must impose additional regulations on polluters to bring the county's air quality into compliance with the standard. While states have some flexibility as to the specific measures they take to reduce pollution concentrations in non-attainment counties, all states must submit a realistic plan to bring the county into attainment with the standard. As a result, polluting firms in non-attainment counties face more stringent environmental regulation than firms in attainment counties.

The Clean Air Act Amendments and an increase in other environmental regulations have in turn motivated a large body of literature examining the consequences of environmental regulation for firms. For example, Greenstone (2002) and Greenstone et al. (2012) utilize the variation created by the Clean Air Act Amendments to estimate the effects of environmental regulation on employment, capital, output, and total factor productivity.

Much empirical work has found that environmental regulation increases innovation. Popp (2010) provides an overview of the literature related to environmental regulation and incentives for innovation.[2] However, very little research has examined how firms transfer knowledge from innovations within the firm. Learning is difficult to observe, primarily because networks of knowledge are difficult to identify. Moreover, since learning usually takes place over a significant period of time, measuring learning is difficult and the benefits may be slow to materialize. For instance, in a study of the cost effects of health information technology adoption, Dranove et al. (2012) demonstrated the problem of measuring average effects when learning is involved. While the adoption of electronic medical records is associated with a small increase in average costs, an examination of the cost effects by year after adoption reveals that a large start-up cost drives this result and that the technology actually reduces costs over time. In this paper, we provide a unique lens to examine innovation and learning by taking advantage of the structure of the geographic variation created by the NAAQS and by estimating the dynamic effects of these regulations.

The NAAQS are likely to have competing effects on technical efficiency, potentially reducing efficiency of plants while simultaneously providing opportunities for firms to increase efficiency. There are at least two mechanisms through which environmental regulation reduces efficiency. The installation of pollution abatement equipment, required by many regulatory schemes, decreases the technical efficiency of plants. Additionally, regulations create new constraints for the optimizing plant. If plants are minimizing their costs prior to a regulation, then these constraints cause a reallocation of resources away from the efficient, optimal allocation. Of course, the effects of regulation may not all be negative. Plants may innovate in response to the pressures of environmental regulation, as suggested by Popp (2003). For example, regulation may call attention to existing inefficiencies in plants as suggested by Porter (1991) and Porter and van der Linde (1995). These innovations may be efficiency-enhancing, and can offset some of the negative effects of resource reallocation and abatement on efficiency.

Moreover, if the same firm owns both regulated and unregulated plants, environmental regulation may also affect the technical efficiency of some of these unregulated plants. Throughout this paper we refer to an electricity generator in a non-attainment county as a "regulated" plant and an electricity generator in a non-attainment county and an "unregulated" plant. We use this terminology for brevity and clarity; however, note that all electricity generators face some degree of environmental regulation. Therefore, no plants in our sample are truly "unregulated", even if they are located in attainment counties. Therefore, in this paper, "regulated" means more stringently regulated through non-attainment of the NAAQS and unregulated means less stringently regulated through attainment of the NAAQS.

[2] Popp (2003), Jaffe and Palmer (1997), Brunnermeier and Cohen (2003), Popp (2006), and Taylor et al. (2003) examine innovation specifically in the context of the Clean Air Acts. Linn (2008), Johnstone et al. (2010), and Hamamoto (2006) study the effects of related environmental regulations on innovative outcomes.