Some Causal Effects of Innovation and Environmental Policy Interactions

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Estimating the causal joint effect of two policies is rare yet increasingly important in a world where firms simultaneously face multiple, overlapping policies. This is especially true for the energy sector. Environmental policies aiming to reduce emissions often interact with non-environmental interventions, such as innovation incentives, that could also contribute to decarbonization. Hundreds of billions of dollars' worth of public resources are spent globally each year to subsidize research and development (R&D) and innovative activity. How do these support mechanisms shift the *direction* of innovation towards technology and services that help to protect environmental systems? And how do they interact with environmental policies that may also induce innovation in relatively clean solutions by reducing investment risk and uncertainty?

In this paper, we develop three quasi-experimental approaches to examine how the interaction of two major policies in the United Kingdom affect the level and direction of innovation—as measured by financial and environmental performance—in the electricity sector: contracts-for-difference (CFDs) and R&D tax credits. The CFD scheme is the UK's main mechanism for supporting low-carbon electricity generation, whereby renewable energy developers are paid the difference between the average cost of their own renewable generation (i.e., the "strike price") and the average price for electricity in the market (i.e., the "reserve price") per megawatt-hour (MWh) of generation. This protects developers from volatile wholesale prices, greatly reducing uncertainty and investment risk. At the same time, firms can claim generous R&D tax credits that reduce the cost of investing in R&D.

Both schemes provide incentives for firms with renewable electricity assets to innovate, or to invest in ways that could improve their economic and environmental performance. Understanding their interdependencies is therefore critical for optimal energy innovation policy design but it is empirically difficult due to simultaneity and selection bias concerns. Identifying the causal *joint* effect requires sources of exogenous variation in each policy that do not confound each other. Furthermore, measuring innovation in the power sector is non-trivial. Energy is a commodity, and generators typically use technologies developed and (perhaps) patented by other firms. They are more likely to innovate in ways that may not involve patenting. As such, we measure innovation outcomes by operational, financial, and environmental performance improvements.

We begin by combining a regression discontinuity design (RDD) with OLS to essentially estimate a "discontinuity-in-effects" (DiE). First, we use a sharp discontinuity in the R&D tax credit rate to identify the causal effect of R&D tax credits on electricity suppliers, as firms under an exogenous total assets threshold set by the policy are eligible for more generous tax credits than those that are just over the threshold. This threshold was set strictly for the R&D tax credit generosity purposes and firms in the power sector do not appear to strategically manipulate their assets to take advantage of the higher rate. We do not directly observe whether firms apply for and receive tax credits, but we assume that most electricity generators invest in some sort of R&D and claim the tax credits, with those just under the threshold benefitting from higher subsidy rates.

Next, we estimate the effect of the CFD strike price that each generator faces—which varies across technology classes and within-generator over time—separately on each side of this tax credit generosity threshold. The interaction effect is the *difference* in the estimated CFD effects at the tax credit rate discontinuity. Although CFD prices are endogenously determined by budget availability and technology type, identification of the interaction effect only requires that firms just under the R&D tax credit threshold do not respond to the CFD strike price systematically differently relative to those just over the R&D tax credit threshold. As long as the endogeneity of CFD prices operates in

the same direction and with a similar magnitude for firms on each side of the tax credit generosity threshold, the interaction is identified. This holds given the research design validity that we can show for the RDD on its own.

Second, we combine the R&D tax credit RDD with another RDD for a "discontinuity-in-discontinuity" design so that we can identify the causal effect of CFDs independently as well. The CFD scheme offers generating capacity phased CFDs for offshore wind projects of up to 1,500 MW, providing more generous CFD support for projects under the capacity threshold. We use this in another RDD to estimate the CFD impact. To extend this to study the interaction with R&D tax credits, we test whether this discontinuity is different for firms under the R&D tax credit generosity threshold relative to those above it.

Third, we also estimate the impact of these support mechanisms and interactions on firms that do *not* receive CFD support but which are directly affected because they finance it (e.g., relatively dirty fossil fuel generators). Doing so is important for understanding the *net* effects on clean versus dirty innovation. We combine an instrumental variable (IV) approach to identify the CFD effect with the RDD for the tax credit effect. Payouts by non-CFD firms are determined by the difference between the strike price and electricity market price for each MWh of generation, and the market price is partially driven by weather-based variation. The non-CFD generators typically use the Low Carbon Contracts Company's Transparency tool to forecast the CFD Supplier Obligation. We interpret the difference between forecasts relative to actual payouts as "shocks" to expectations and use them to identify the CFD impact on non-CFD firms. As before, we estimate these IV regressions separately below and above the R&D tax credit threshold to recover the interaction effect as the difference between the IV estimates at the threshold. We are also exploring the possibility of using machine learning methods to develop generator-specific forecasts as an alternative method for measuring expectation shocks.

We plan to match several datasets to carry out these analyses. We obtained generator- and company-level data for the UK power sector from Aurora Energy Research, a private energy data analytics company. The dataset includes hourly, daily, and monthly information on operations, economic performance, and environmental performance. This provides us with our innovation outcome measures and detailed operational data. We will match this to Bureau van Dijk's Financial Analysis Made Easy database for firm characteristics that determine eligibility for the tax credit scheme and additional financial performance variables. Finally, we will match this to the CFD auction registry databases for information on each generator's technology type, location, and strike price.

At this stage, we do not have preliminary results to share. Our progress thus far has focused on developing the three quasi-experimental research designs and building our dataset. We have, however, confirmed that we will be able to carry out the analyses described with the data we have collected, as there is a sufficient number of electricity suppliers with total assets both below and above the tax credit generosity threshold as well as the offshore wind CFD eligibility threshold. We have also started to explore many of the key research design elements to confirm that they are valid under standard assumptions, such as no manipulation of total assets, which is critical for all three research designs.

This paper aims to make three main contributions. Perhaps most importantly, the first contribution is methodological, as we focus on estimating the causal joint effect of two endogenous policies by developing three quasi-experimental approaches. This is rare in the literature. Firms often face multiple mechanisms simultaneously and thus understanding potential interdependencies is critical for optimal policy design in many settings. Second, we hope to provide new empirical evidence on the Porter Hypothesis, shedding light on the role of both environmental and technology policies for the environmental and financial performance of the power sector. Finally, decarbonizing the energy sector is critical for avoiding the climate change damages that threaten humanity. Doing so cost-effectively will require tremendous innovation. We therefore hope that this paper will contribute towards a better understanding of how policy can steer the direction of innovation and firm performance in the electricity sector.