Bringing Breakthrough Technologies to Market: Evidence from Reducing Revenue Risk in the UK Renewable Electricity Market

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Achieving net-zero emissions by mid-century cannot be achieved without significant investments in frontier technologies that reduce greenhouse gas emissions. Even in spite of strong societal imperatives, the time in bringing breakthrough technologies to market is long. Deploying frontier technologies is risky: firms sometimes face large upfront costs and uncertainty over future demand, price, and regulatory conditions. When these risks interact with market failures like credit constraints or imperfect appropriability, there is under-investment in equilibrium. Given the urgency of climate change, policies that help firms overcome these hurdles can ensure timely and sufficient investment into these technologies.

I develop a two-stage dynamic firm entry model to show how high fixed costs coupled with uncertain revenue streams delay firm entry decisions, resulting in less breakthrough technologies deployed in the short term. Greater uncertainty for new technologies raises the cost of capital as financiers are risk averse, reducing the number of profitable draws in equilibrium. In a real options framework with irreversible investments, investors choose to wait until there is more certainty on uncertain parameters. This "waiting" is problematic when the technologies in question are associated with reducing negative externalities or generating large positive externalities. I show how policies which reduce revenue risk, such as by guaranteeing a fixed price, can bring forward entry decisions and result in more investment in breakthrough technologies in equilibrium.

To test the model, I estimate the role of one such novel policy: the UK's "contract-for-differences" scheme (CfDs), widely credited with kickstarting the off-shore wind industry locally and elsewhere. The UK's "contract-for-differences" (CfDs) scheme was introduced in 2013 to support relatively under-developed low-carbon technologies such as offshore wind, remote island wind, advanced conversion technologies (which create energy from biomass or waste), and biomass with CHP. A CfD contract removes price risk by paying low-carbon power generators a fixed "strike price" for their mega-watt hours of generation over a 25-year period. If the market rate for electricity is *below* the strike price, generators are paid the difference and if it is *above*, generators pay the difference.

I create a comprehensive dataset of generator-level investment, innovation, financial performance, emissions, and power output. Monthly data on the financial and operational performance of power generators in the UK from 2010 to 2021 is merged with patent counts from PATSTAT, balance sheet information from BvD Fame, emissions from the EU ETS register, financial deals from Pitchbook and Zephyr, and idiosyncratic information about each generator from government databases.

I implement two research designs to estimate the causal effect of CfDs on investments into frontier technologies, notably to investigate whether the scheme increased the diversity of investors, decreased the cost of capital, and brought on investment in the earlier stages of the project.

First, on the extensive margin, I use matched differences-in-differences to examine how recipients of a CfD contract perform relative to non-CfD low-carbon generators that are similar in all other respects apart from receiving a risk-reduction policy. Second, I investigate the intensive margin by regressing the outcomes on the strike price. The strike price is decided via a sealed bid auction where bids from

aspiring participants are ranked in ascending order. The last bid to exhaust a pre-determined government budget sets the strike price for all generators within a specific "technology pot". As the strike price is set by an "outlier", it is exogenous to the majority of CfD recipients. There is also significant heterogeneity in costs across projects due to geographical factors, such as the cost of acquiring a site and building; and the degree of experimentation involved with specific parts of the technology.

This work makes several contributions to the literature: (i) it generates quantitative evidence on the impact of risk-reducing policies in incentivising frontier innovation, (ii) it causally infers the effect of contract-for-differences on the environmental, operational, innovative and financial performance of generators, thereby contributing to an ongoing debate about whether this scheme was the determinant of the success of UK's offshore wind market, (iii) it makes a theoretical contribution to the literature on investment under uncertainty, couching it in the context of irreversible investments in intermittent power generation, and (iv) it adds to a broader literature on stimulating investment in industries that are price-takers in volatile commodity markets.

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