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The impact of a Carbon Tax on the CO_2 emissions reduction of wind

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Energy policy aims to reduce emissions at least long-run cost while ensuring reliability. Policies to support wind or solar PV, improve efficiency, or shift peak demand need to be assessed on the cost of the emissions reduced. Ofgem (2018) in its *State of the market 2018* is a good example, comparing the cost effectiveness of various UK energy policies. This paper shows how to estimate CO_2 reductions in electricity from wind deployment in both the short and long run. Both need to be estimated to adequately measure carbon savings.

Clearly, just how much wind and other renewables reduce emissions will depend on the carbon price and the types of plant on the system. The carbon price will affect the merit order and influence which plant type runs, and hence on the fuel and carbon that wind displaces. The main EU instrument for setting the price of CO_2 is the Emissions Trading System (ETS). From plausible levels of the allowance (EUA) price of €20-30/tonne in 2008, the price sharply declined after the *Renewables Directive* reduced demand without withdrawing EUAs, and for long periods of time after 2012 has remained well below €10/tonne, at which level it has little effect on the fuel mix.

The UK Government has committed to tough carbon limits in the UK *Climate Change Act 2008* and introduced a Carbon Price Floor (CPF) in the 2011 Budget that applies to fossil fuels used to generate electricity. To implement the CPF, the Treasury publishes the Carbon Price Support (CPS, a carbon tax in addition to the EUA price) based on forward EUA prices at the time of the autumn budgets to come into effect at the start of the fiscal year in the following April. The CPS was revised several times to bring the total carbon price up to the announced CPF trajectory that was planned to reach £(2011) 30/t by 2020 and £(2011) 70/t by 2030. After the failure of other EU countries to either reform the ETS or impose a similar CPF, the Government froze the CPS in 2016 at £18/tCO_2 until 2021.

The impact of this considerable increase in the cost of fossil fuel for electricity generation has been dramatic. Before the introduction of the CPS coal generation was cheaper than the most efficient Combined Cycle Gas Turbines (CCGTs), so that gas was the marginal fuel in the mid-merit part of the market. After the introduction of the CPS coal eventually became the most expensive fossil fuel (in April 2015, when the CPS increased from £9.55/tCO2 to £18.08/tCO_2), causing a massive switch from coal-fired generation to gas. The share of coal fell from 41% in 2013 to 6% in 2018. Great Britain (the CPS does not apply in Northern Ireland) therefore offers an excellent test-bed for the impact of a carbon tax (the CPS).

This paper quantifies the impact of the CPS on the carbon savings from wind. Wind is hard to forecast with much accuracy day-ahead when the time comes to decide which types of generation to commit and run. As wind varies from moment to moment, the carbon displaced will depend on the plant operating and its flexibility. We study this short-run impact econometrically to find the main drivers of the short-run displacement achieved.

Policies are chosen for their long-run impact. Governments set targets for the future share of renewable electricity and carbon budgets. These policies will affect the future fuel mix, and hence the dispatchable plant available daily. We determine this long-run impact with a unit commitment dispatch model of the 2015 GB system. We examine the effect of increasing wind capacity by varying amounts up to 25%. Long run has the conventional meaning that it is a period over which wind capacity can change, in contrast to the short run in which wind capacity is fixed but its output varies. We study the impact of the CPS in 2015. The first counterfactual has no CPS, but just the EUA price. The second looks to the CPS in 2018 after the EU Emissions Trading System was reformed, which raised the GB carbon price substantially above its 2015 level.

The econometric models estimate the marginal (coal and gas) displacement of wind (in MWh coal or gas/MWh of wind). Given this, we estimate the short-run marginal displacement factor (SR-MDF) of wind on emissions, tonnes CO_2/MWh wind. There are two main advantages for this approach: first, it explains the underlying mechanisms that drive the dynamics of the MDF; second, it allows us to study the counterfactual, i.e. what if the CFS is not implemented or what if it were higher? We are unable to deliver the counterfactual without knowing the underlying drivers.

The econometrics also estimates the impact of demand changes on emissions as the Marginal Emissions Factor (MEF in tonnes CO_2/MWh). Multiplying the MEF by the CPS provides an estimate of the impact the CPS on the wholesale price, which could be used to study the impact of the CPS on interconnector flows and revenues — the topic of a later paper.

Results

A simple examination of the evolution of the fuel mix over time strongly suggests that gas has displaced coal, and that wind has displaced both, but as the clean spark and dark spreads have varied substantially over time with varying fuel and carbon prices, a more detailed examination was undertaken to tease out the various effects.

The short-run impact of varying wind half-hourly on the fuel mix and emissions was explored econometrically, using changes in fuel and carbon prices as well as in wind output and final demand over 2012-17 to create sufficient variation to identify the drivers of the half-hourly marginal displacement of wind. The econometric study suggests that the short-run MDF of wind depends on the electricity demand (i.e. which fuel type is running at the margin), the merit order, and the flexibility of fossil plants. Specifically, when demand is low, base load plant responds more strongly to short-run wind changes. However, when demand is high and so is its variability, more flexible plants (i.e. CCGTs) are preferred for responding to wind changes. Because of this, CCGTs dominate as the (short-run) marginal fuel during peak hours (07:00-23:00) regardless of the merit order, while coal would only be the (short-run) marginal fuel during off-peak hours (23:00-07:00) when coal provides the base load. Consequently, as the CPS switches the merit order, coal becomes the mid-merit fuel but not the peak-hour marginal fuel, making CCGTs the marginal fuel for the entire day. Because of the much lower carbon intensity of gas, the SR-MDF decreases from 0.44 tCO_2/MWh in the counterfactual absence of the CPS in our reference year, 2015, to 0.41 tCO_2/MWh with the CPS. The EU Market Stability Reserve sharply raised carbon prices in 2018, and in our counterfactual of a total GB carbon price of £37/tCO_2, the SR-MDF falls further to 0.36 tCO_2/MWh. In each case the MEF is either the same or slightly higher than the MDF.

The unit commitment simulation model is able to explore the effect of different total carbon prices on the carbon savings from a significant increase (25%) in installed wind capacity, holding fuel prices constant. This showed that with 2015 gas and coal prices, introducing the CPS as an additional £18/tCO_2 on an EUA price of £6/tCO_2 switched coal from base-load to mid merit, making it somewhat more responsive to increasing wind penetration due to changes in wind capacity, slightly increasing the long-run carbon benefits of more wind. The LR-MDF rises from 0.50 tCO_2/MWh with no CPS to 0.60 tCO_2/MWh with the CPS. Increasing the total carbon price further, however, leads to a decrease in coal generation, resulting in a smaller decrease in emissions with increases in wind capacity (because coal plants are either running at zero or minimum load) to a LR-MDF of 0.57 tCO_2/MWh. The LR-MDF is systematically higher (by 15% with no CPS to 46% with the CPS) as the unit commitment model assumes new wind turbines would only displace fossil plants in the long-run, while in the short run, both pumped storage and interconnectors can adjust to half-hourly wind changes.

Both the simulation and the econometrics confirm that the impact of wind depends quite sensitively on the state of the system — which plant are running and whether they are constrained by minimum loads, capacity, or ramping limits. That in turn depends on fuel and carbon prices and the levels of residual demand. Different countries have very different plant mixes, and so the carbon benefits of additional renewables capacity will also vary, while over time, fuel and carbon prices as well as the plant mix will also vary. This paper shows how the emissions benefits can be measured for a given plant mix and set of fuel and carbon prices, implying that country level detailed modelling will be needed to understand their impacts. The long-run impact of increasing wind *capacity* is largely captured by the LR-MDF, although there will be some short-run variability that will, at least with our estimates based on GB conditions, somewhat reduce these values as more flexible gas is required to address unpredicted fluctuations in residual demand.

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