Estimating the impact of wind generation on balancing costs in the GB electricity markets

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Agenda

- Introduction
- Review of literature
- Data and methods
- Results
- Conclusion

Introduction

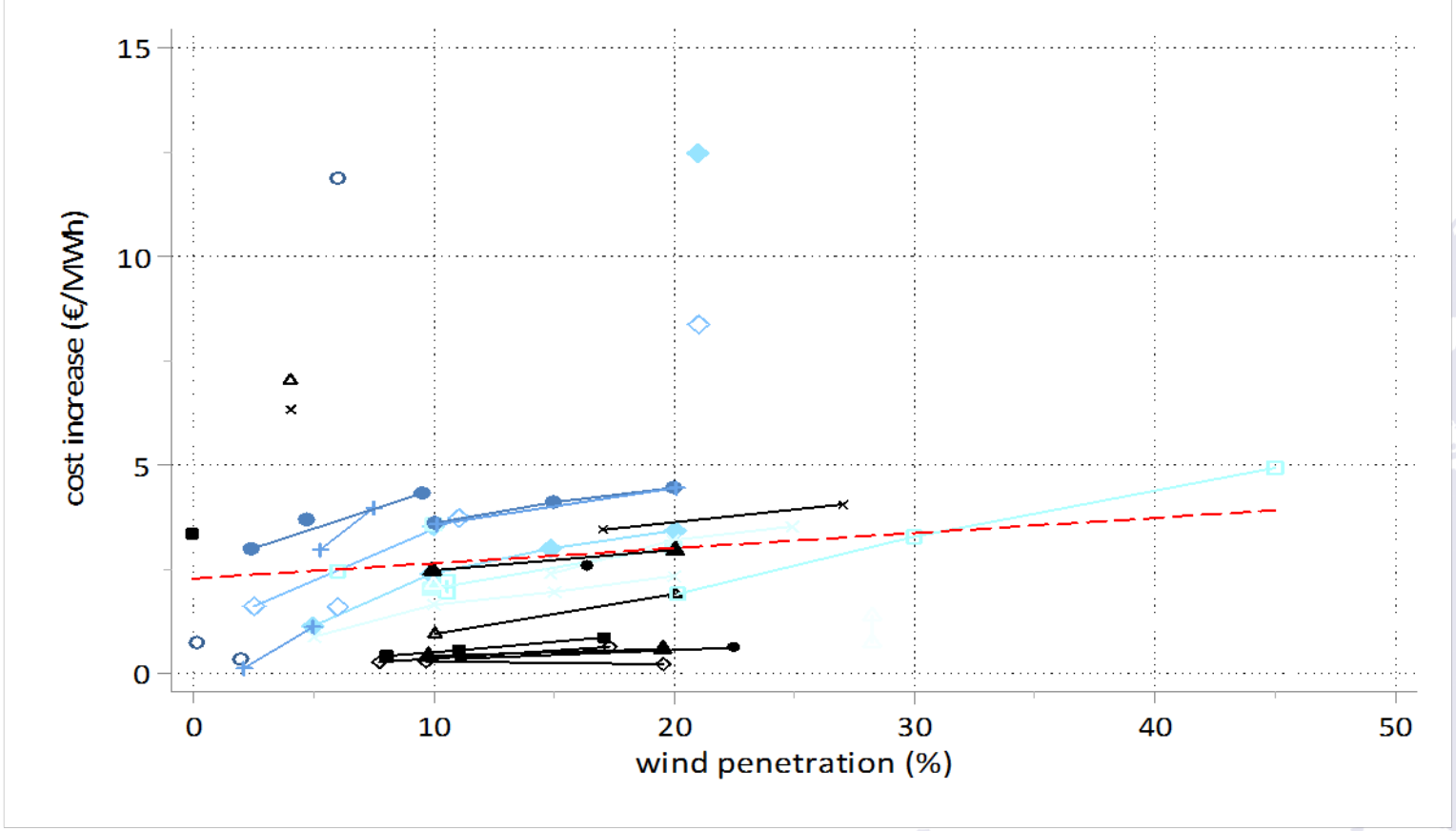
- Wind expected to play large part in meeting renewables targets of many EU countries especially UK
- Intermittency of wind and cost a major issue
- Wind will impose external costs on power system
  - Three main types of system costs
    - Balancing
    - Security of supply/reserves
    - Grid
  - Some overlap between all three
- GB balancing costs made up of deviations from actual day-ahead schedule to one-hour before real time
  - System operator averages flexible unit offers to top-up or spill power to form system buy price and system sell price (SBP and SSP)
- As wind penetration grows actual data becoming available

Previous research

- Previous research has focused on a variety of costs
  - but few empirical studies
- Existing research has tended to use simulations
  - Difficult for simulations to accurately reflect stochastic conditions of wind and balancing
  - Non-stochastic aspects important too, e.g., actual correlation of wind deviations with demand and generation deviations
  - Importance (and difficulty) of modelling aspects such as interconnectors, outages, pumped storage, also of noted importance

Previous research

- Previous research cost is summarized by the following figure

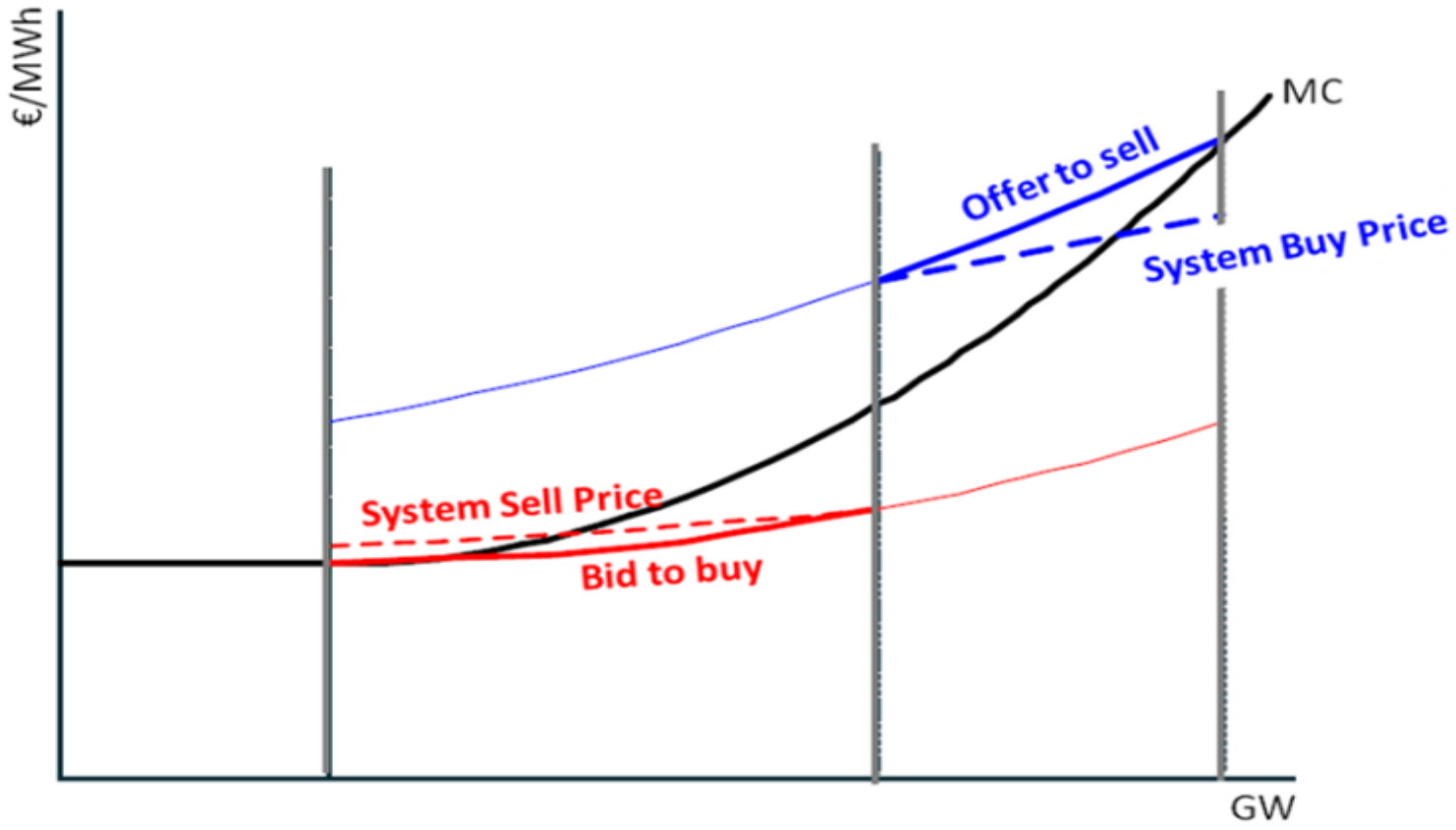


Data and methods

- Data
  - Rich data on actual wind generation on GB system basis available
  - Data from Elexon, the market operator in UK
    - Publicly available online
    - Five minute total generation by fuel type
      - CCGT, OCGT, Coal, oil, wind, pumped storage, nuclear
    - Five minute net flows for each interconnector
      - France, NL, Ireland
    - Demand—but we simulate demand with net gen plus net export
      - Ignores variable transmission and distribution losses
  - Also balancing mechanism reporting agent (BMRA) data
    - System buy price (SBP) (when system is short)
    - System sell price (SSP) (when system is long)
    - Total net imbalance volumes in MWh

Data and methods

- Method is to estimate variable cost function
  - Balancing mechanism mimics variable cost function



Data and methods

- Method is to estimate variable cost function
  - The economic/social cost of balancing arises from
    - the fact that very short-run deviations from the optimal/competitive day-ahead schedule do not lie on the marginal cost curve
    - The convexity of the curve
  - Thus the net of sell and buy is not zero
    - The day-ahead schedule is close to unbiased
      - (i.e., on average not net long or short)
    - But next most expensive unit may not turn off/on first because some units are inflexible

Data and methods

Method

- Assume variable cost of balancing function can be approximated
  - Where
  - SSP (system sell price)
  - SBP (system buy price)
  - V(t) is net balance need (MWh)

- $$C_t = -\frac{1}{2}\left[\begin{array}{c}(ssp_t - sbp_t)V_t|_{V_t>0} + \\ (sbp_t - ssp_t)V_t|_{V_t<0}\end{array}\right]$$

Data and methods

Method

- Assume variable cost of balancing function can be approximated by input prices (SSP and SBP), and generation mix, interconnector flows, and demand
- $C_t = C_t\begin{pmatrix} ssp_t, sbp_t, G_{wt}, G_{CCGTt}, G_{OCGTt}, \\ G_{Ct}, G_{Ot}, G_{Pt}, G_{iFt}, G_{iIt}, G_{iNt}, t, \boldsymbol{D} \end{pmatrix}$
- Estimate log-linear equation of the above using appropriate error structure and quadratic in the prices
  - Half-hourly data indicates strong AR(1) error structure

Results

- Results-summary statistics of the variables

Generation type	Mean	Std. Dev.	Min	Max
Wind	525	494	0	3,011
CCGT	16,673	3,246	2,154	26,475
Coal	11,675	5,807	1,002	26,044
Interconnector FR	427	1,217	-2,056	2,014
Interconnector IE	-242	153	-506	122
Interconnector NL	55	246	-1,212	1,132
Nuclear	7,187	1,137	1,038	9,270
OCGT	4	28	0	716
Oil	40	192	0	2,646
Other	0	0	0	0
Pumped storage	-115	1,068	-2,778	2,480

Results

	OLS		Prais-Winsten	
Variable	Coef.	P>|t|	Coef.	P>|t|
System Sell Price	-221.855	0.000	-212.094	0.000
System Buy Price	229.540	0.000	213.084	0.000
Wind generation	0.950	0.000	0.730	0.000
(Wind generation)^2	-0.00027	0.000	-0.00021	0.016
Coal generation	0.002	0.631	0.025	0.001
Nuclear generation	-0.071	0.000	-0.089	0.004
CCGT generation	-0.023	0.003	-0.064	0.000
Interconnector (FR)	-0.090	0.000	-0.043	0.138
Interconnector (IE)	-0.262	0.000	-0.165	0.158
Interconnector (NL)	0.221	0.089	0.380	0.072
OCGT generation	14.418	0.000	14.803	0.000
Oil generation	-1.673	0.000	-0.717	0.000
Pumped storage gen	-0.345	0.000	-0.024	0.494
APX price	-3.883	0.043	-21.392	0.000
Year	-2.912	0.843	59.147	0.184
Constant	5,267	0.851	-117,571	0.188
Durbin-Watson	0.81	(d*=1.90)	2.00	(d*=1.90)
Adj R-squared	0.61		0.49	
F(15, 50975)	5,277.83	0.00	3,271.89	0.00

Results

Results-derived outputs

- $\frac{\partial C}{\partial W} = 0.730 - (2)(0.00021)W$

Variable	Year	Observ's	Mean	Total Annualized
Δ(cost)/Δ(wind) (€)	2008	2,928	0.573	1.9m
Wind generation (GWh)			0.378	3,319
Δ(cost)/Δ(wind) (€)	2009	17,520	0.573	1.9m
Wind generation (GWh)			0.379	3,321
Δ(cost)/Δ(wind) (€)	2010	17,520	0.556	2.1m
Wind generation (GWh)			0.420	3,682
Δ(cost)/Δ(wind) (€)	2011	13,007	0.359	2.8m
Wind generation (GWh)			0.896	7,851

Conclusions

- Study novel in that uses actual data and estimation for something subject to stochastic impacts, correlations among variables, changing conditions
- Average marginal impact of wind on balancing €0.513/MWh
  - Lower than other studies (€1-4/MWh)
  - But pure balancing costs, does not include other system impacts
    - Spinning reserve
    - Constraints, losses, etc.
- Balancing cost of wind per unit of generation
  - Not large in absolute sense < €3m
  - Not large per unit energy
- But limitation of the study is not able to add additional costs of losses, constraints, and capital costs

Conclusions

- Conclusion
- More work needed on wind system costs including
  - Cost of reserve capacity
  - Cost of very short term system balancing
  - Other costs
  - Need to track over time as system capacity profiles change