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How large should a portfolio of wind farms be?

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The issue

- The output from wind farms is risky
  - Hour-to-hour and year-to-year variation
- Correlations generally fall with distance
- A portfolio should be better than a single wind farm
- System operators worry about hour-to-hour variation
  - Doherty *et al* (*IEEE Trans. Power Systems,* 2006)
  - Roques *et al* (*Energy Policy,* 2010)
  - Rombauts *et al* (*Renewable Energy,* 2011)
- Investors may have longer time horizons

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Our approach

- Calculate annual profitability and risk for wind stations
- Model hourly prices and outputs using 18 years of wind and demand data
  - Merit order stack for price-setting
  - Capacity based on near-term forecasts
  - Plant costs from five recent studies (UK×3, EIA, IEA)
  - Constant fuel prices from UK government predictions
  - Demand level normalised (before weather) across years
  - Wind output estimated from BADC wind speed data, given 11 GW of onshore and 19 GW of offshore plant

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Generators

	Capacity (GW)	Marginal Cost (£/MWh)
Wind (onshore)	11.0	0.00
Wind (offshore)	19.0	0.00
Nuclear	6.0	5.00
Coal (new)	0.0	42.02
Coal (old)	11.5	53.25
CCGT (new)	15.8	60.03
CCGT (2000s)	8.0	66.82
CCGT (1990s)	7.0	72.28
Oil	0.0	120.49
OCGT	1.0	167.73

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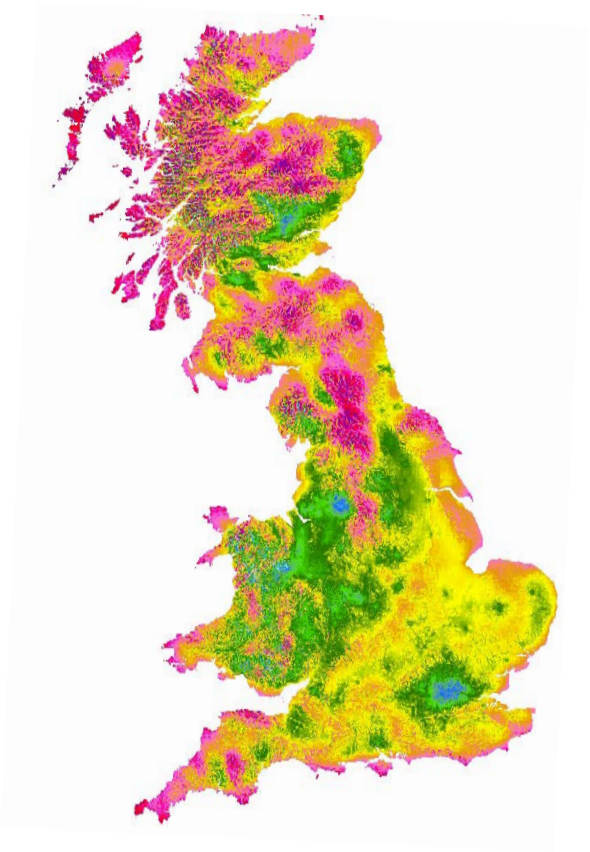
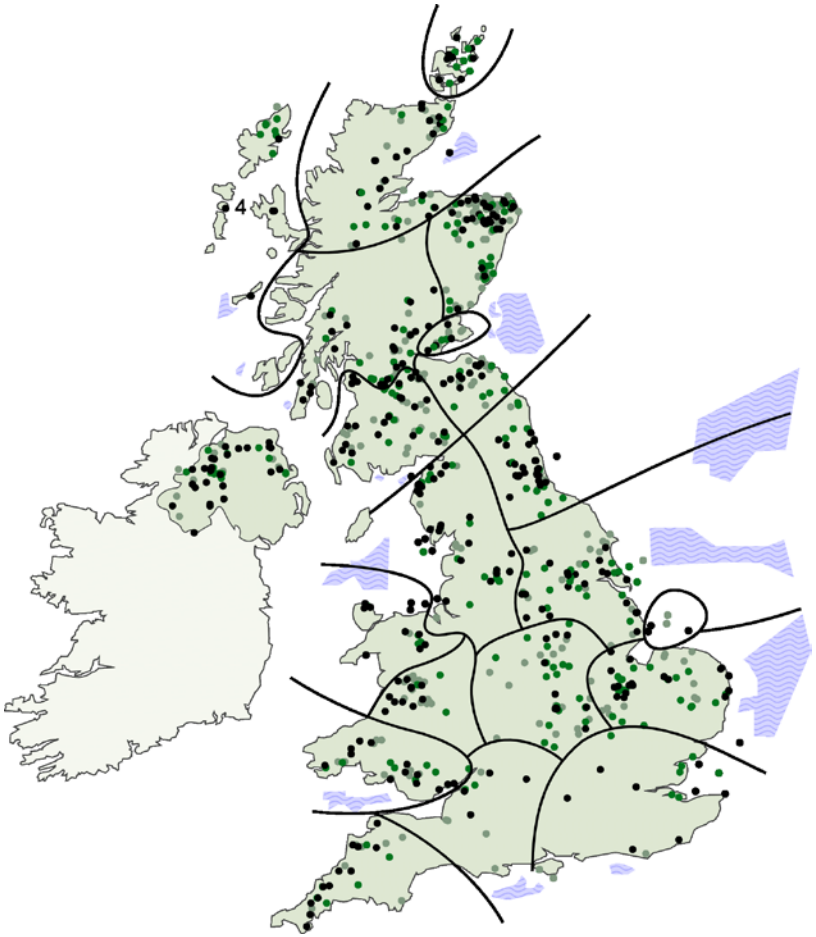
Wind farms around the UK



Wind resource map
Source: GL Garrad Hassan



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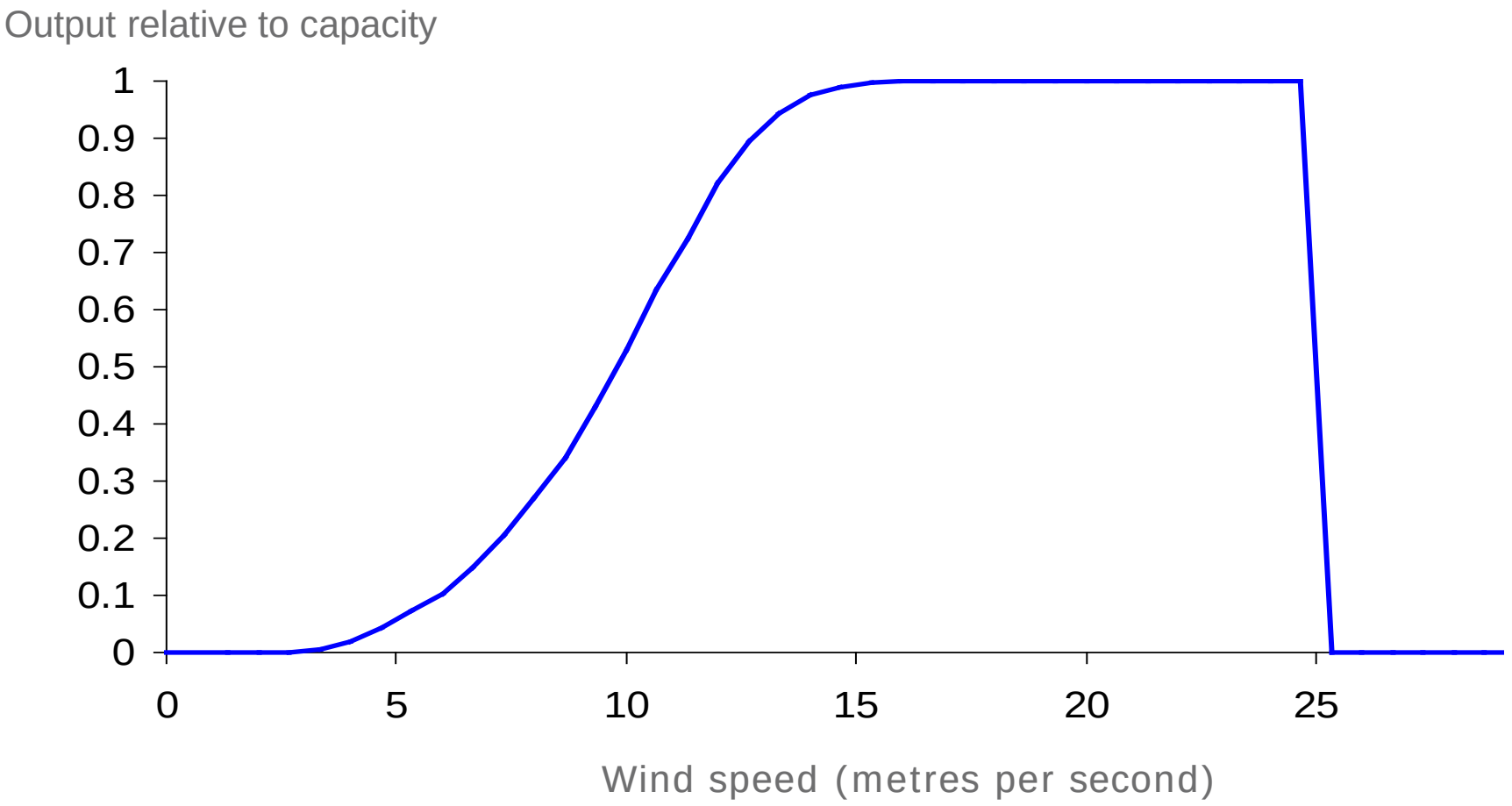
Wind turbine power curve



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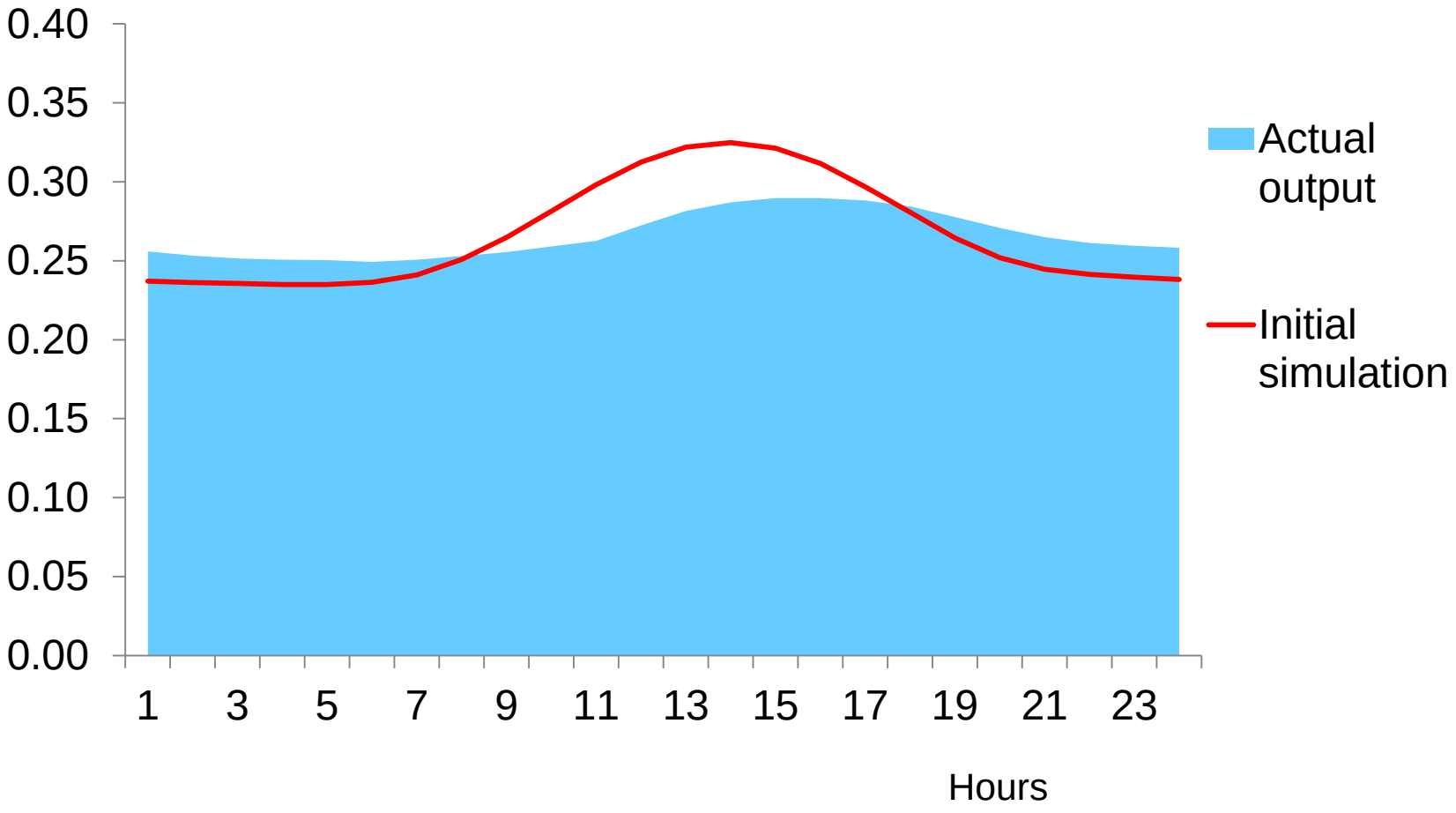
Correcting wind speeds – annual average



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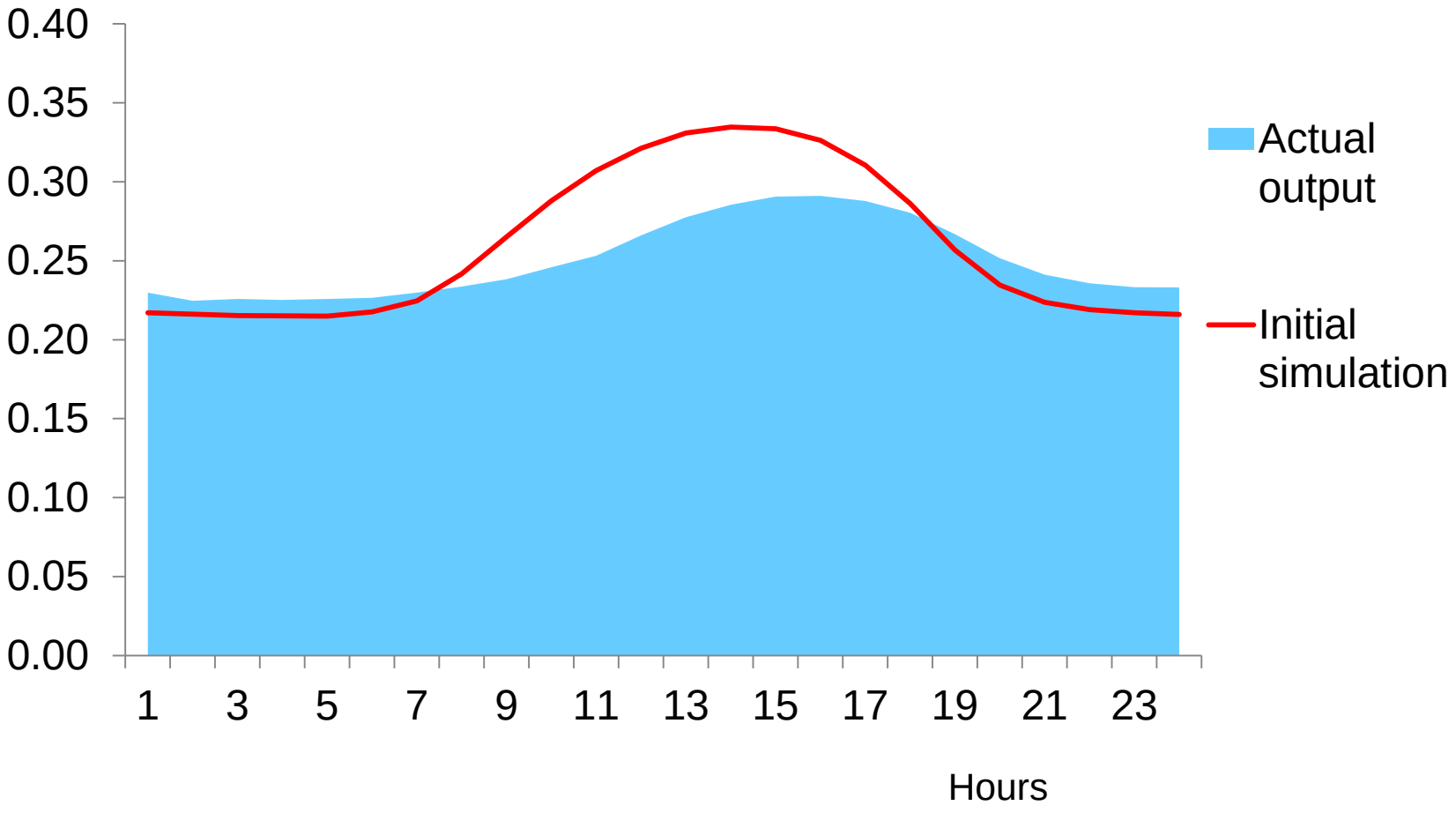
Correcting wind speeds – Spring



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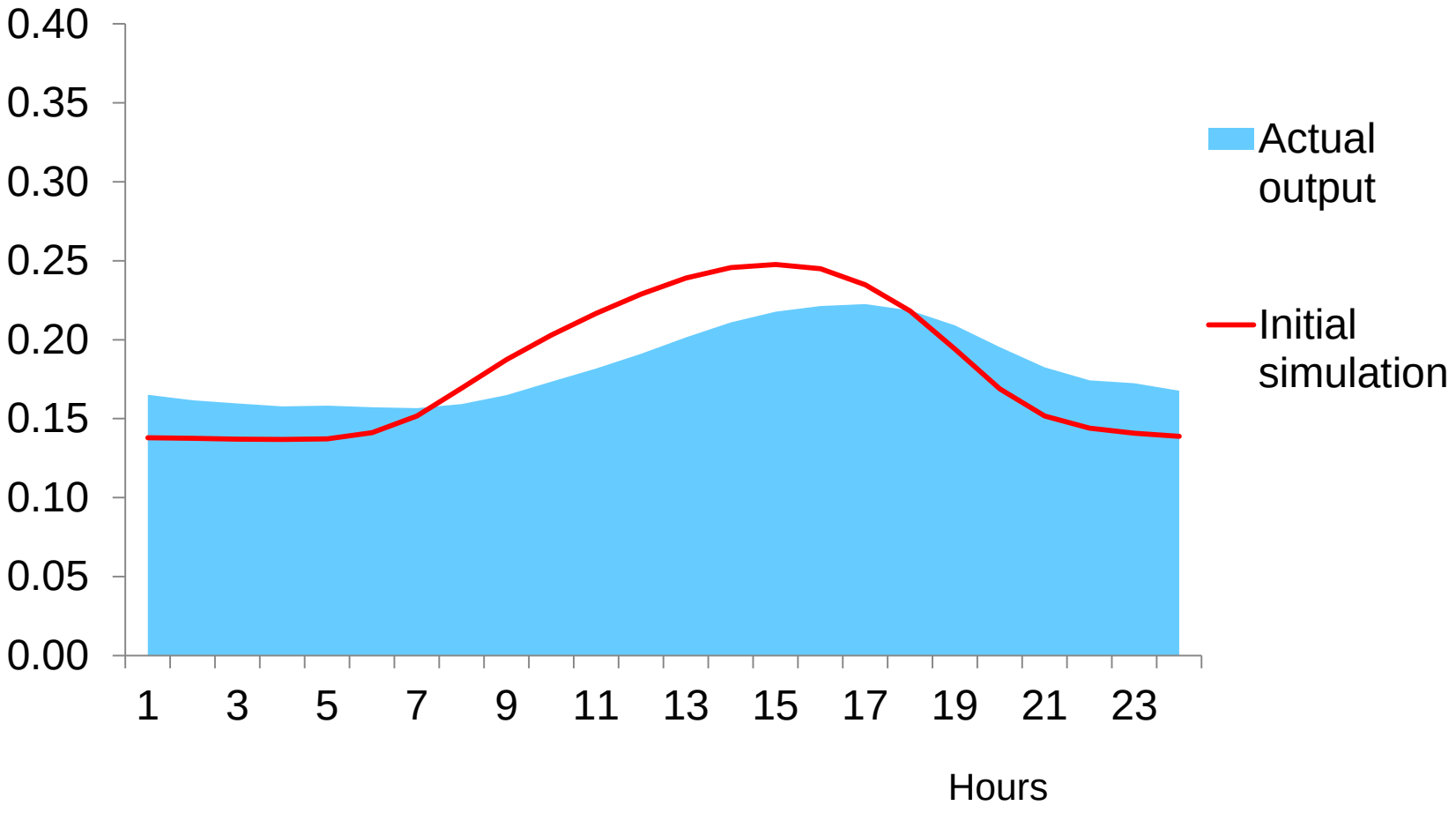
Correcting wind speeds – Summer



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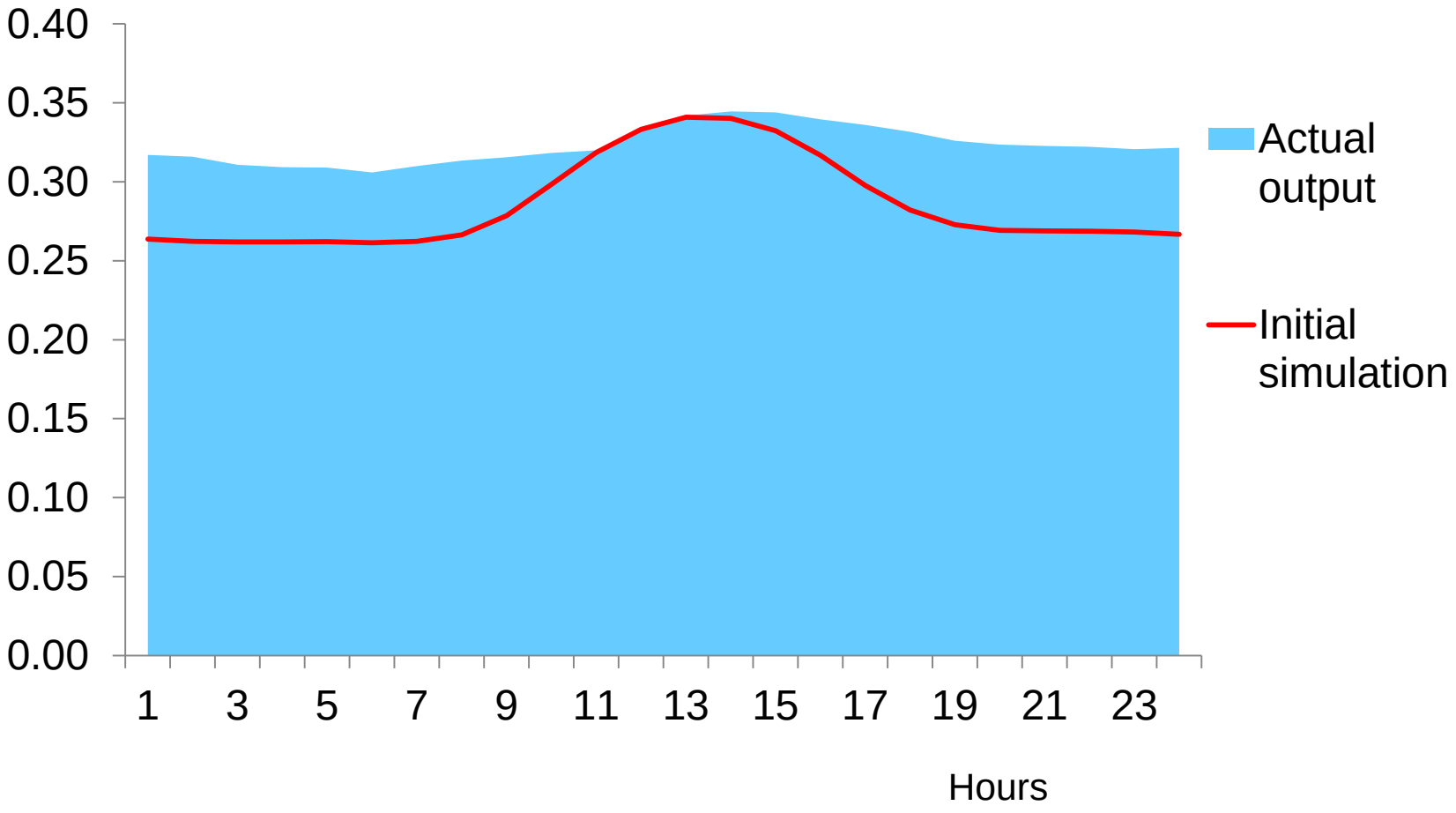
Correcting wind speeds – Autumn



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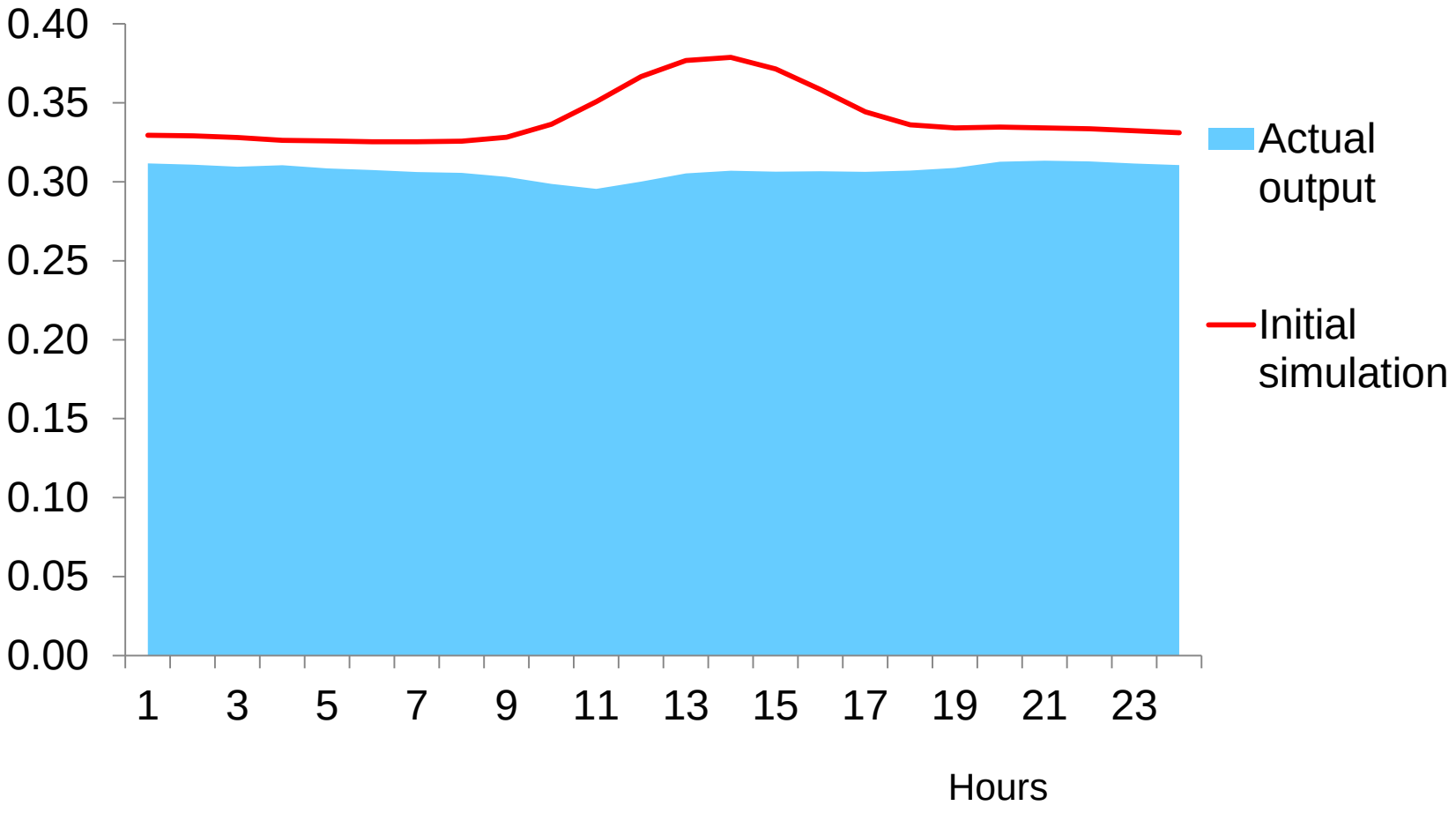
Correcting wind speeds – Winter



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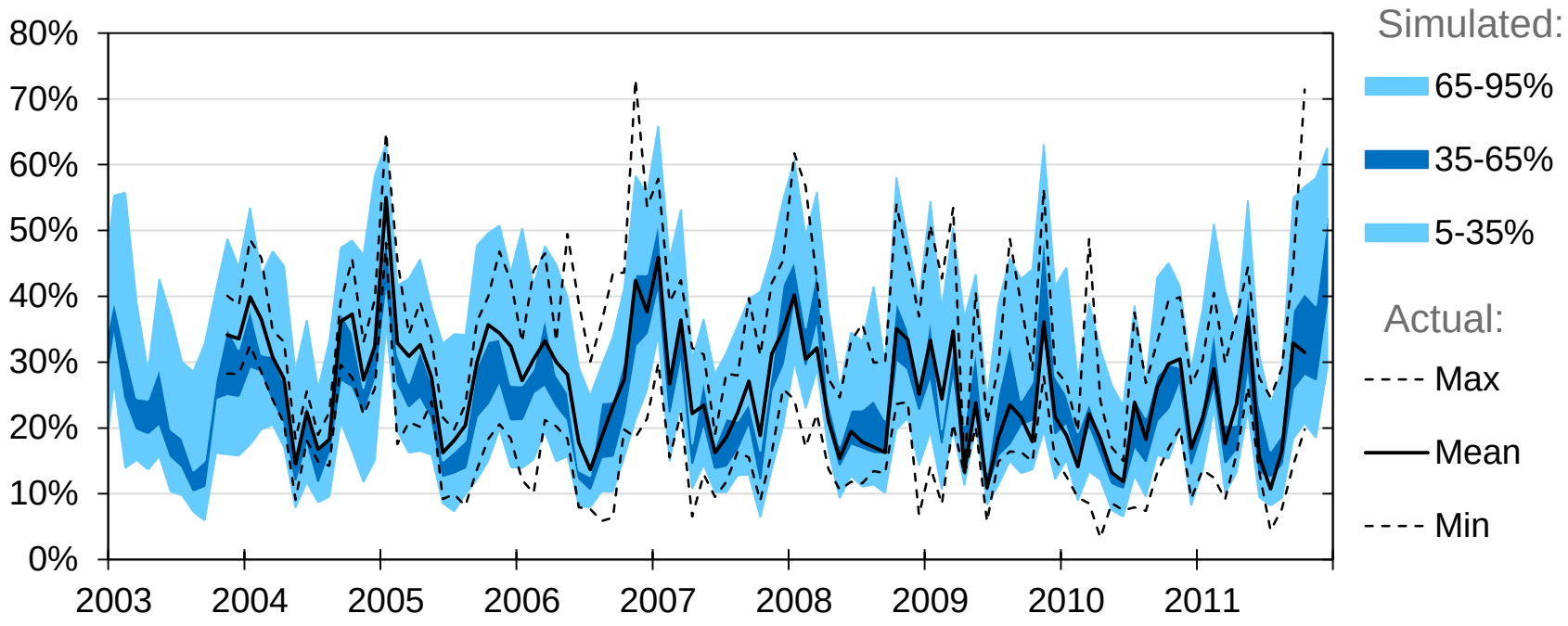
Validation: monthly load factors



Actual load factors from Elexon and Ofgem ROC Register

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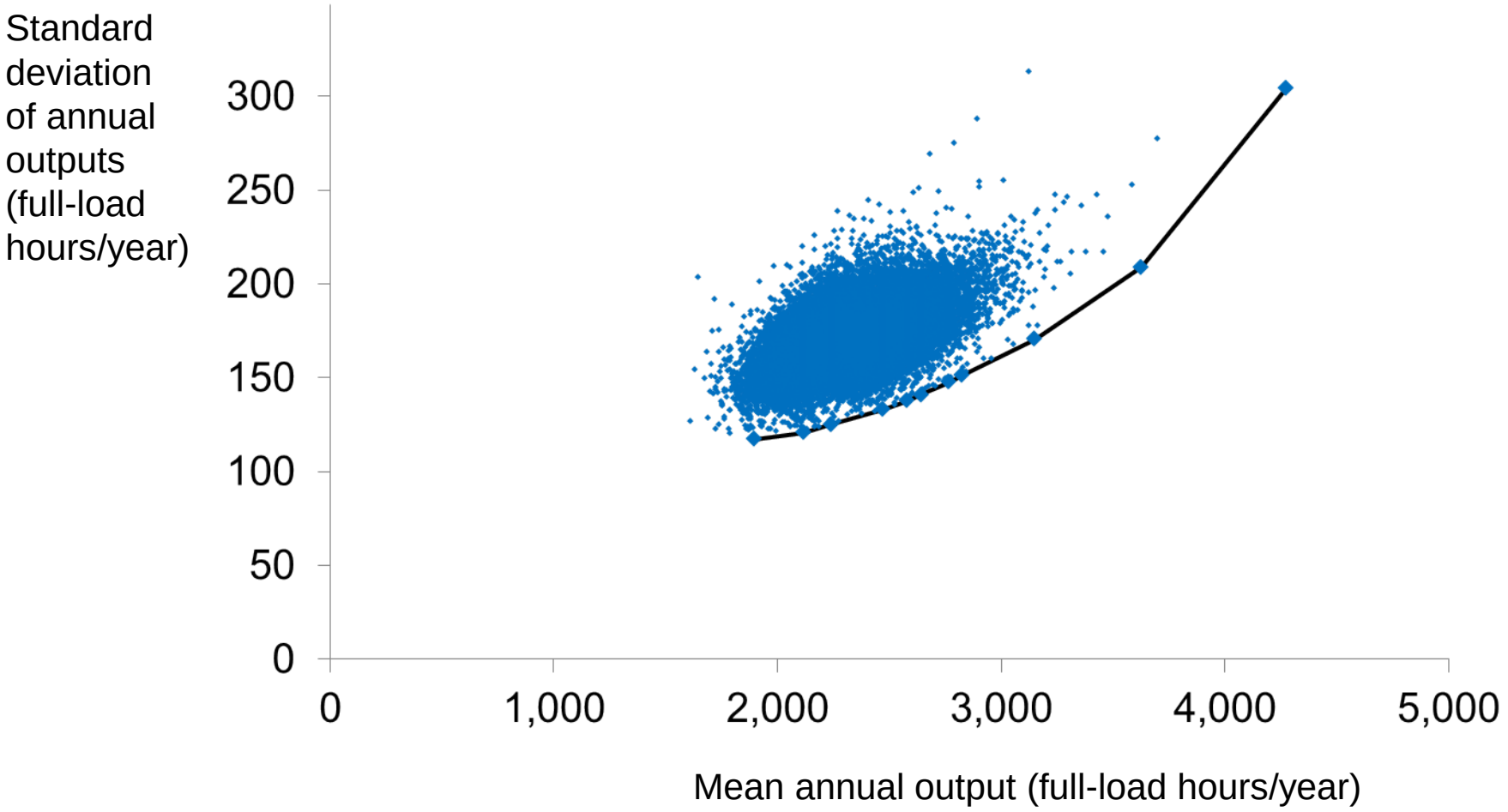
Mean and Standard Deviation of Annual Outputs



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Calculating profits

- Revenues come from prices equal to the marginal cost of thermal plant plus Renewables Obligation Certificates worth £50/MWh
- Annual cost assumed to be £208 per kW
  - Mostly capital costs; also fixed O&M costs
- Mean (super-normal) profit is £38/kW-year
- Standard deviation (across the years for one station) has a mean of £22/kW-year

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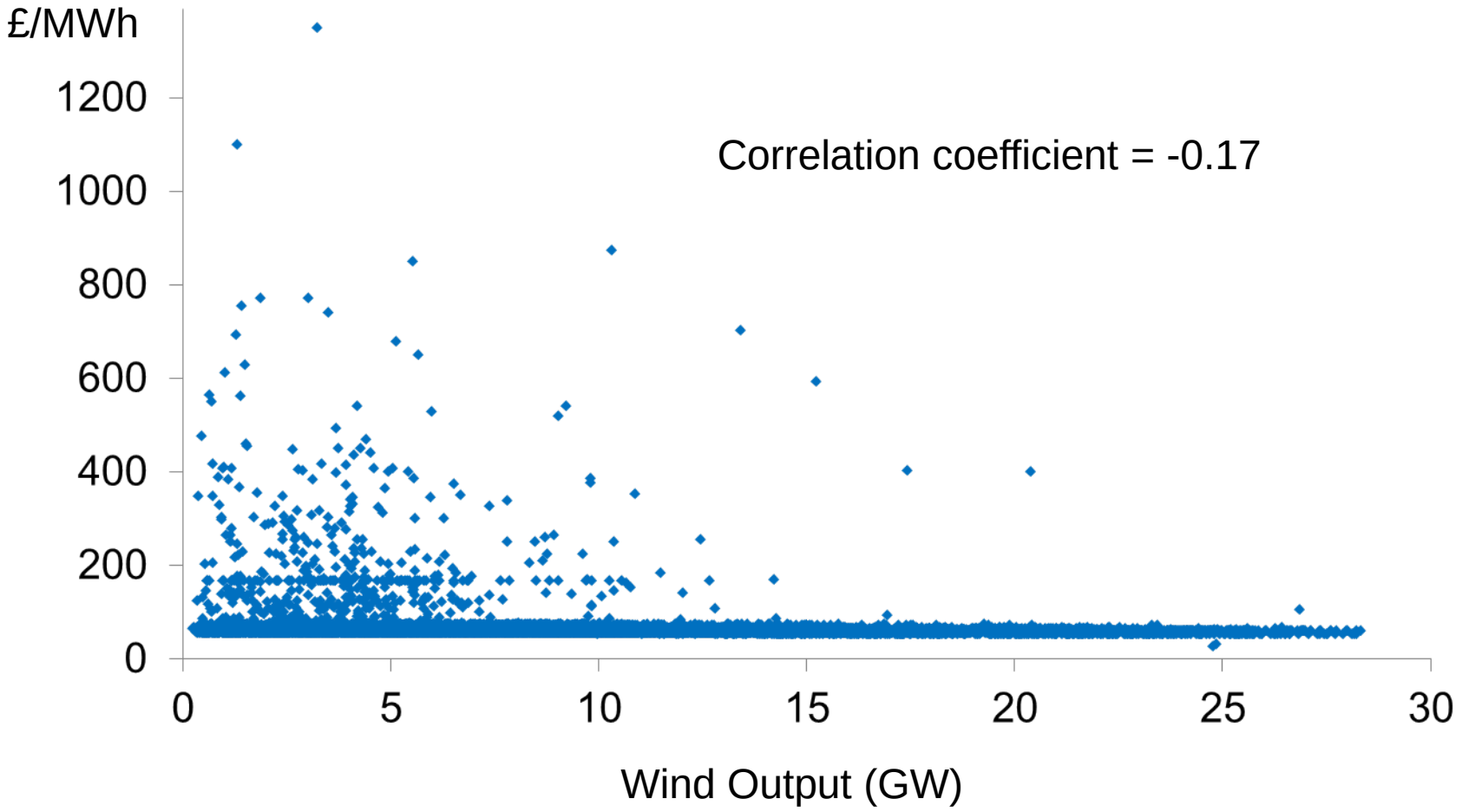
Wind output and market prices



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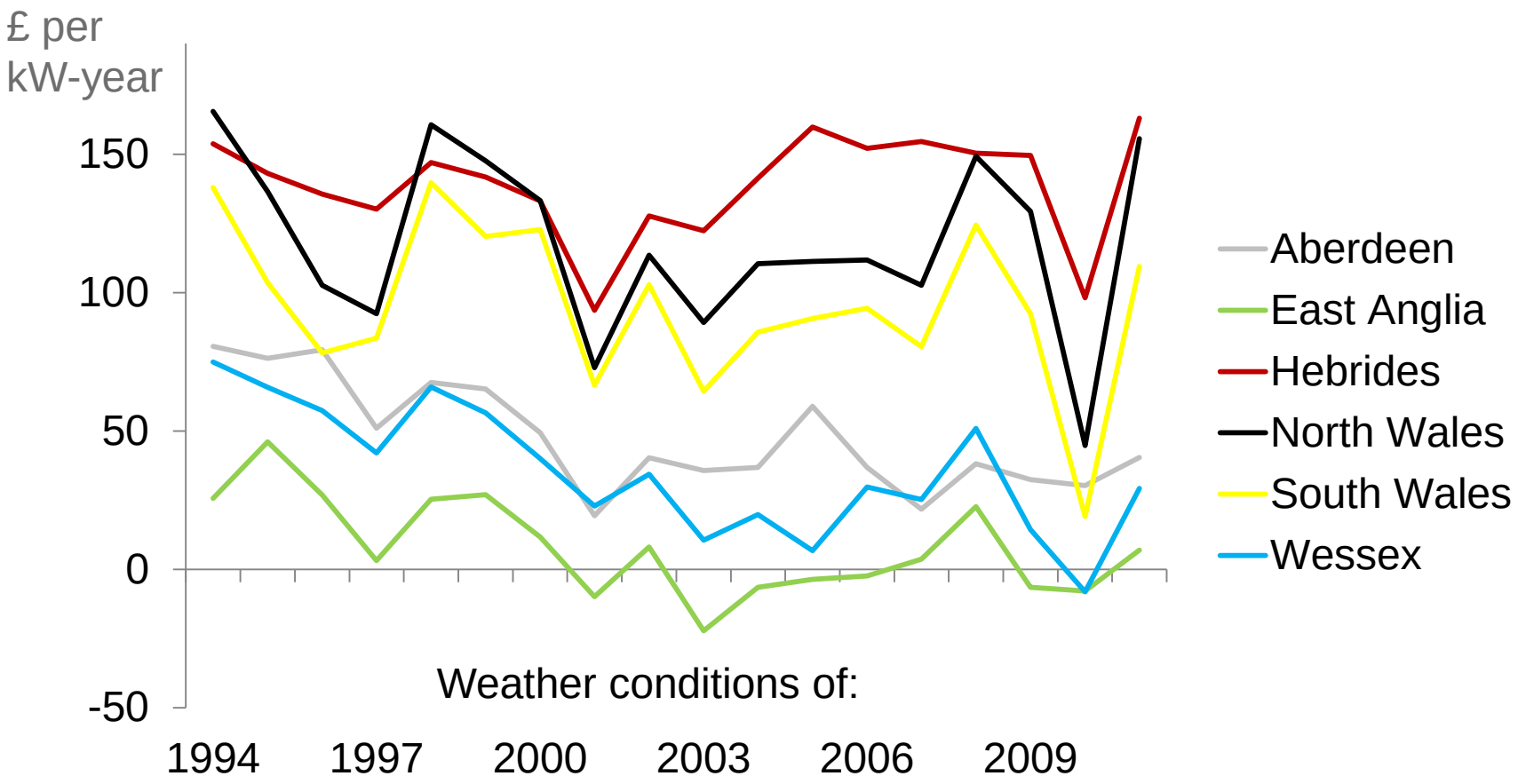
Annual profits by wind farm region



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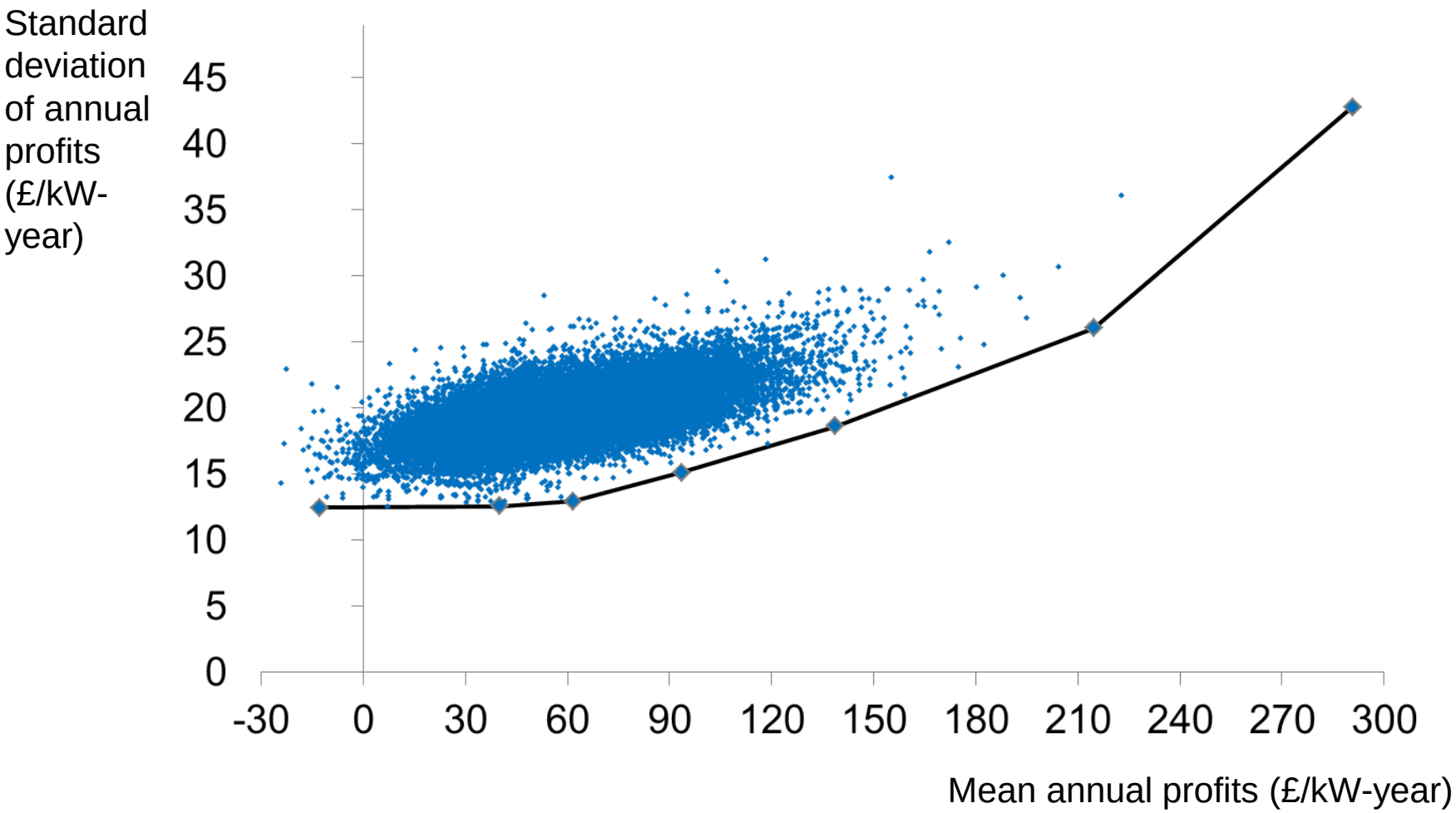
Risk and return from portfolios of wind farms



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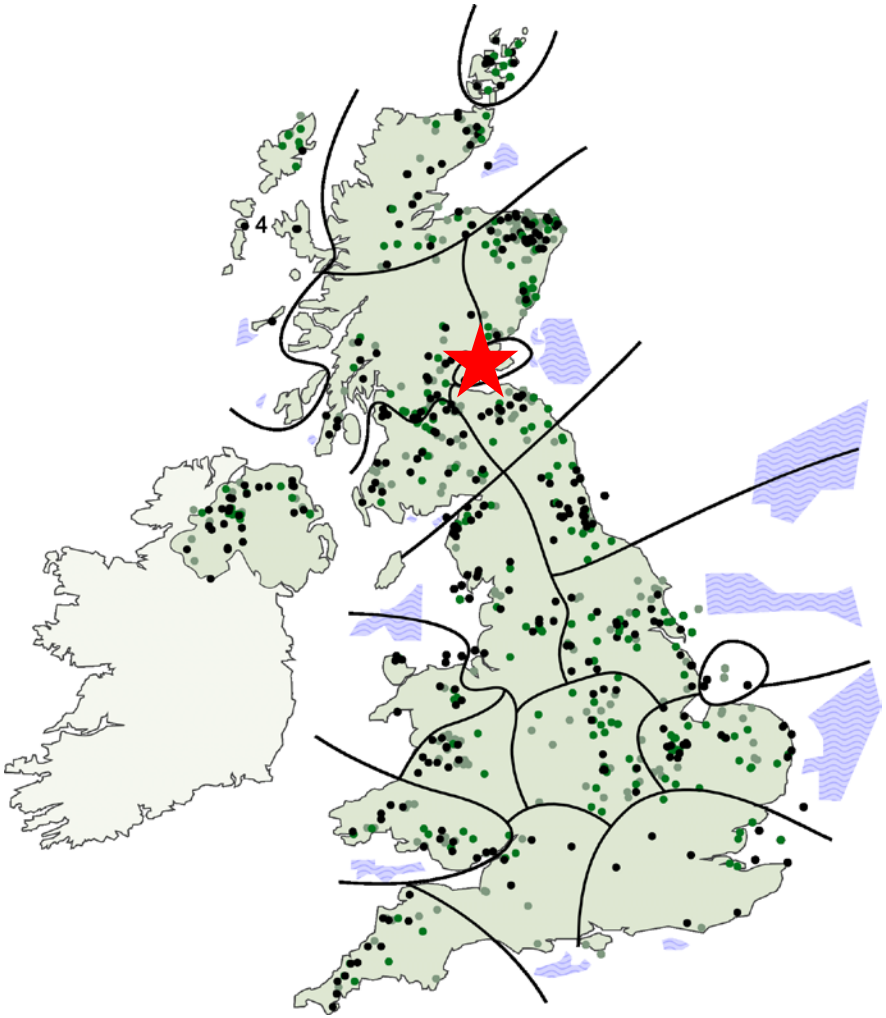
Optimal portfolios of wind farms



	Mean Profit (£/kW-year)	Standard deviation (£/kW-year)
★	291	43

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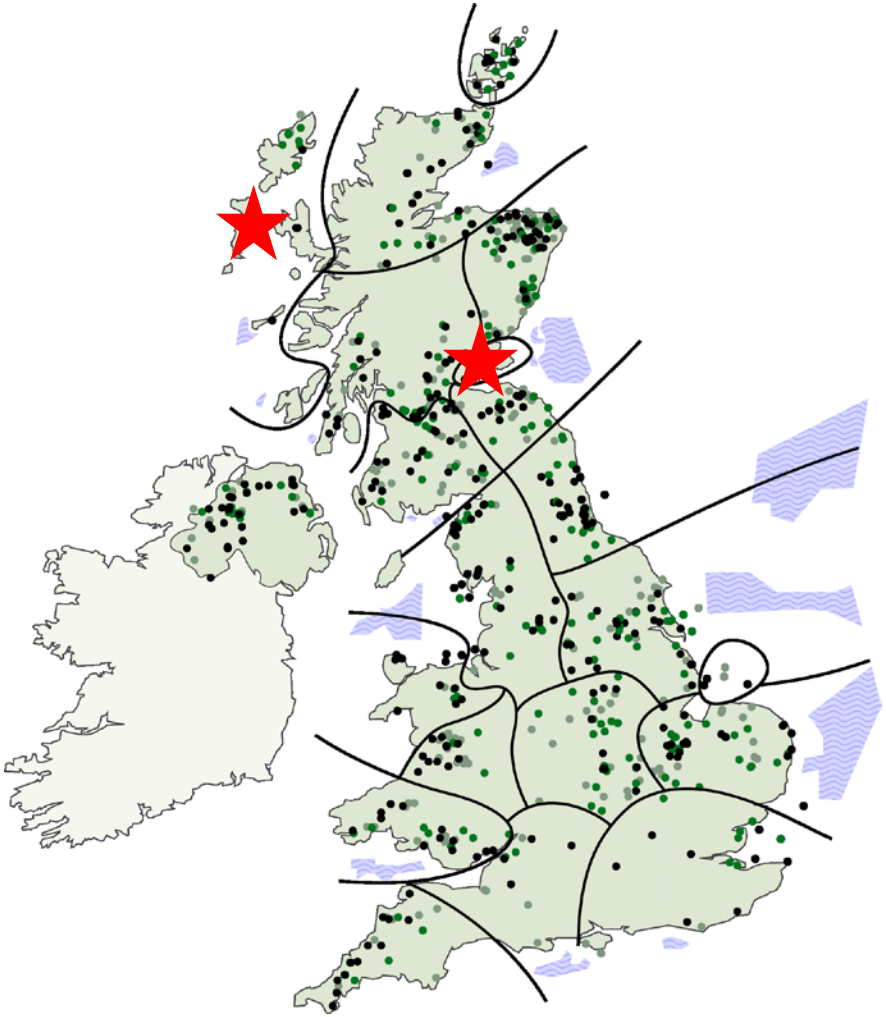
Optimal portfolios of wind farms



	Mean Profit (£/kW-year)	Standard deviation (£/kW-year)
	291	43
★	215	26

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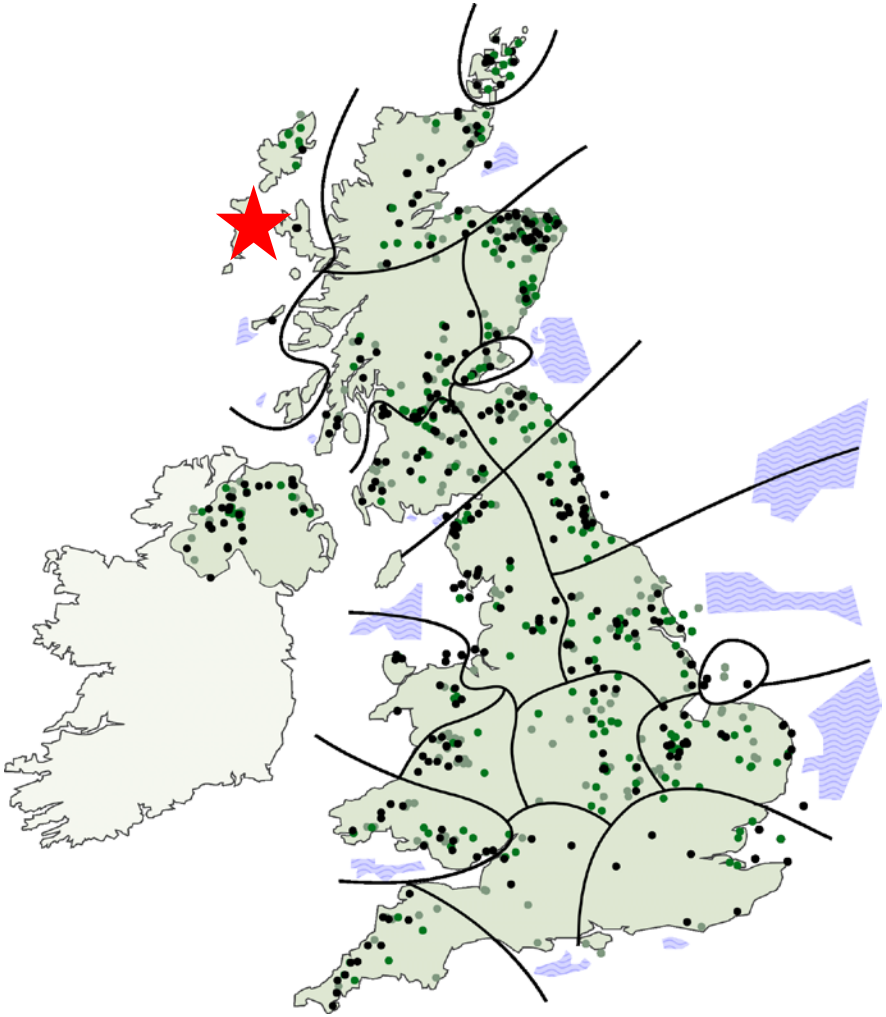
Optimal portfolios of wind farms



	Mean Profit (£/kW-year)	Standard deviation (£/kW-year)
	291	43
	215	26
★	139	19

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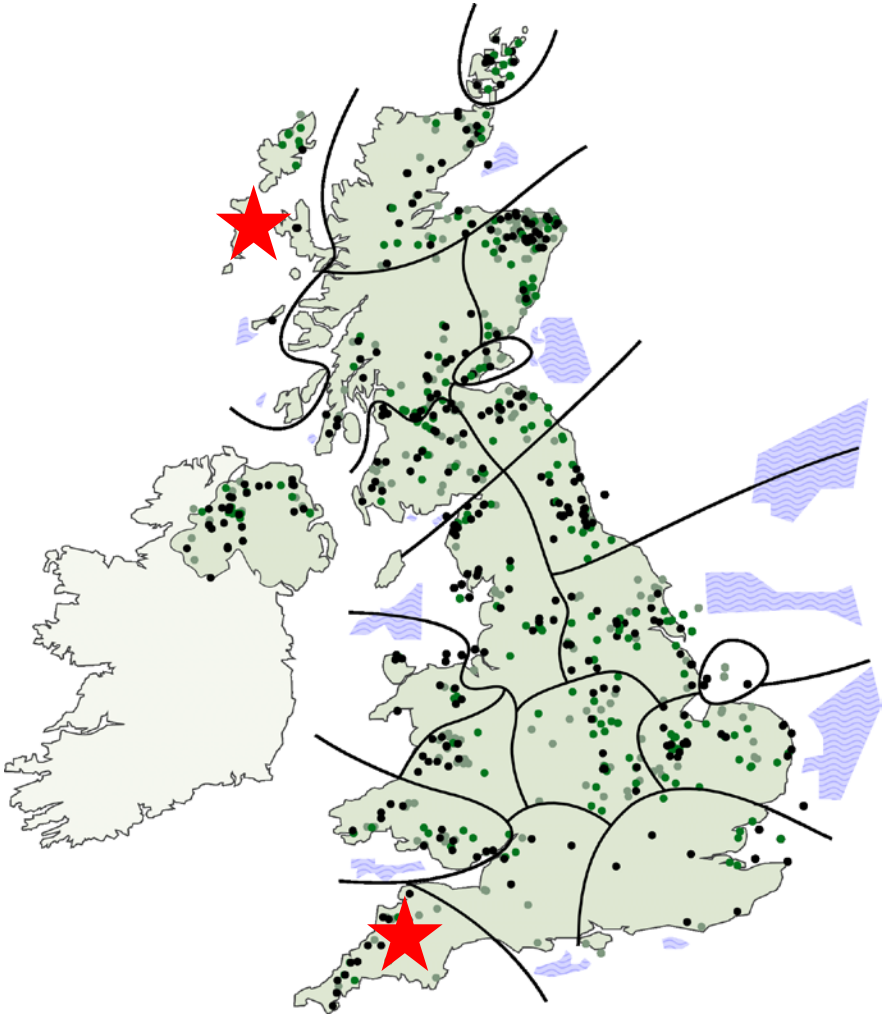
Optimal portfolios of wind farms



	Mean Profit (£/kW-year)	Standard deviation (£/kW-year)
	291	43
	215	26
	139	19
★	93	15

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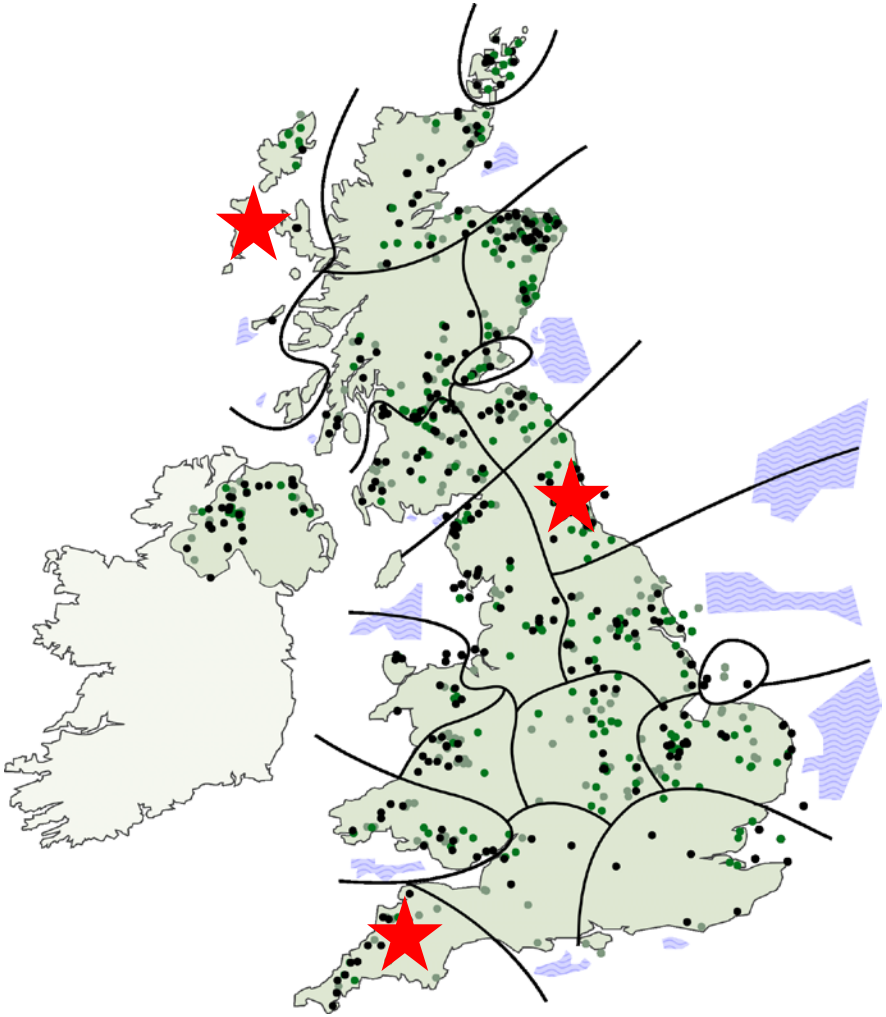
Optimal portfolios of wind farms



	Mean Profit (£/kW-year)	Standard deviation (£/kW-year)
	291	43
	215	26
	139	19
	93	15
★	62	13

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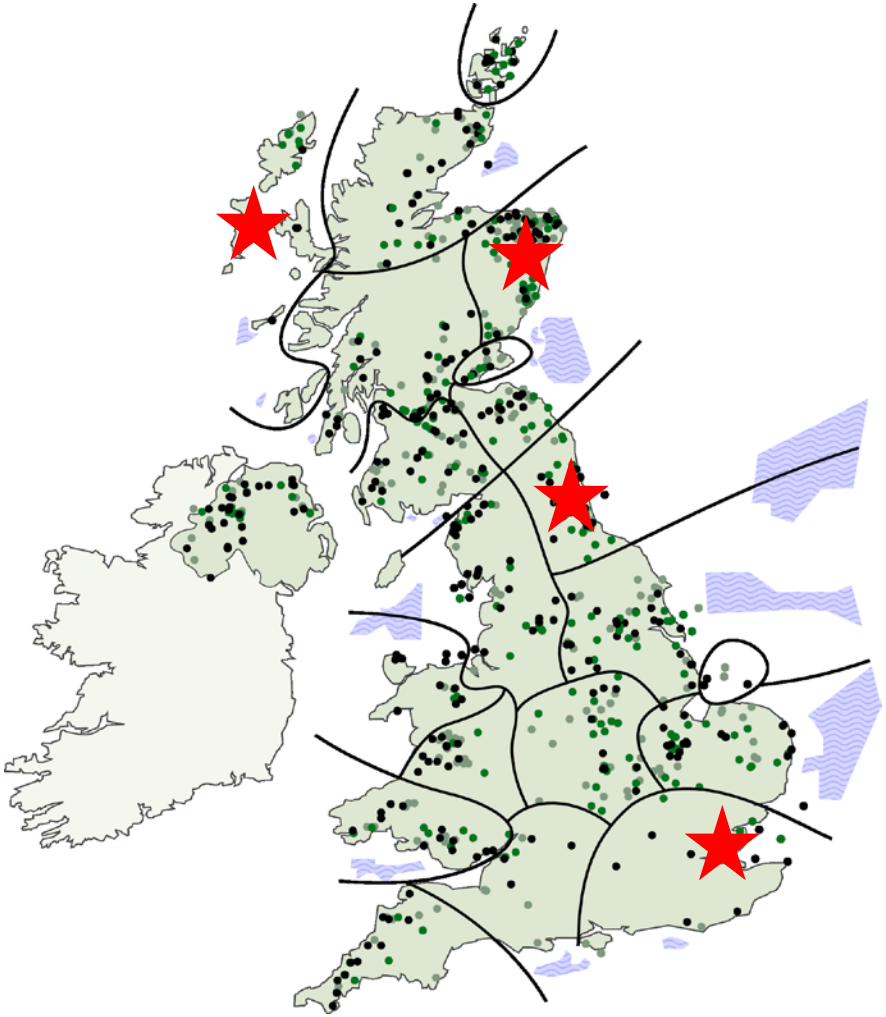
Optimal portfolios of wind farms



Mean Profit (£/kW-year)	Standard deviation (£/kW-year)
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215	26
139	19
93	15
62	13
★ 40	13

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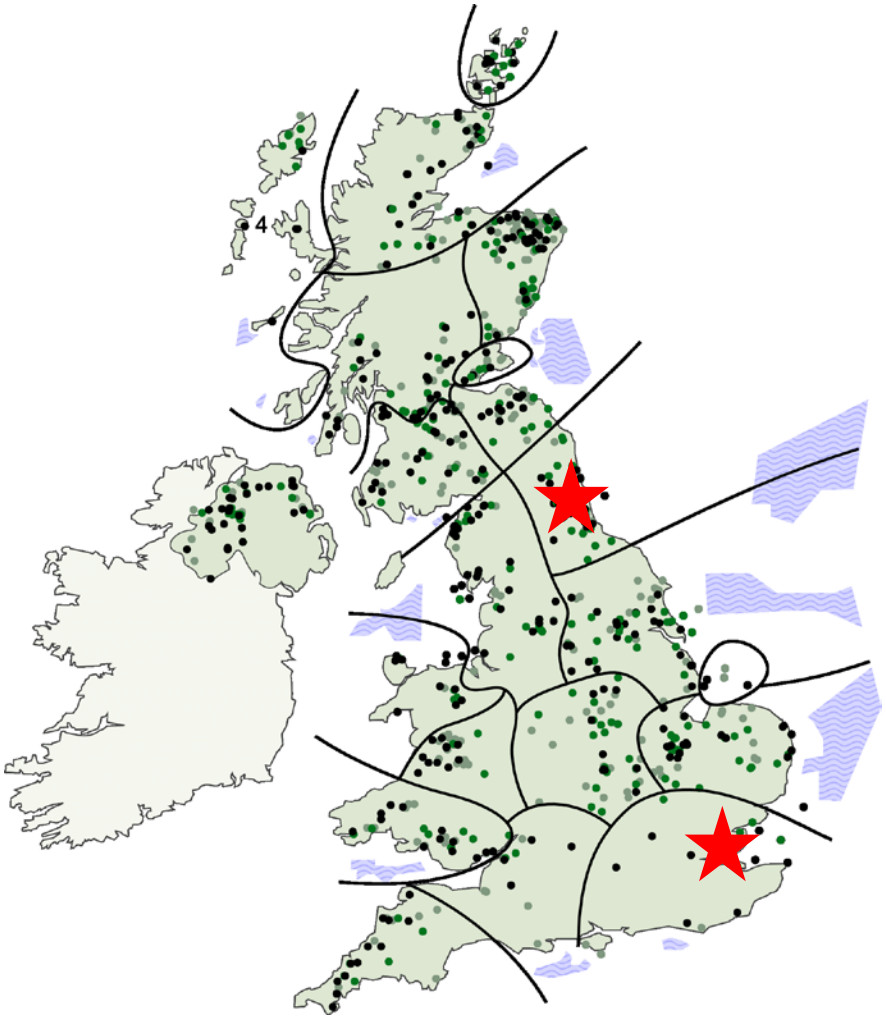
Optimal portfolios of wind farms



Mean Profit (£/kW-year)	Standard deviation (£/kW-year)
291	43
215	26
139	19
93	15
62	13
40	13
★ -13	12

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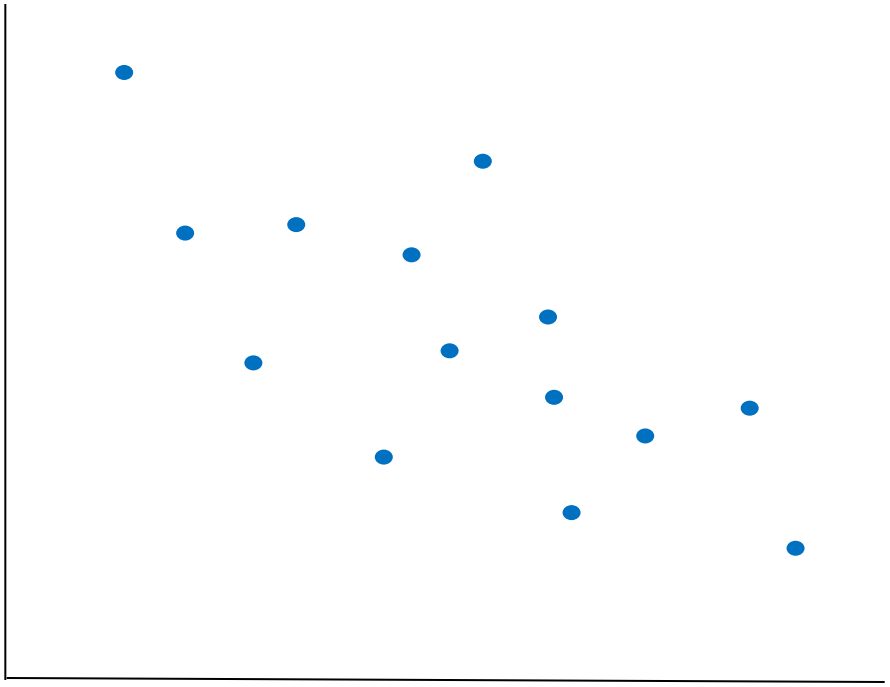
A measure of efficiency

Capital per unit of output



Labour per unit of output

Farrell, (*Journal of the Royal Statistical Society*, 1957)

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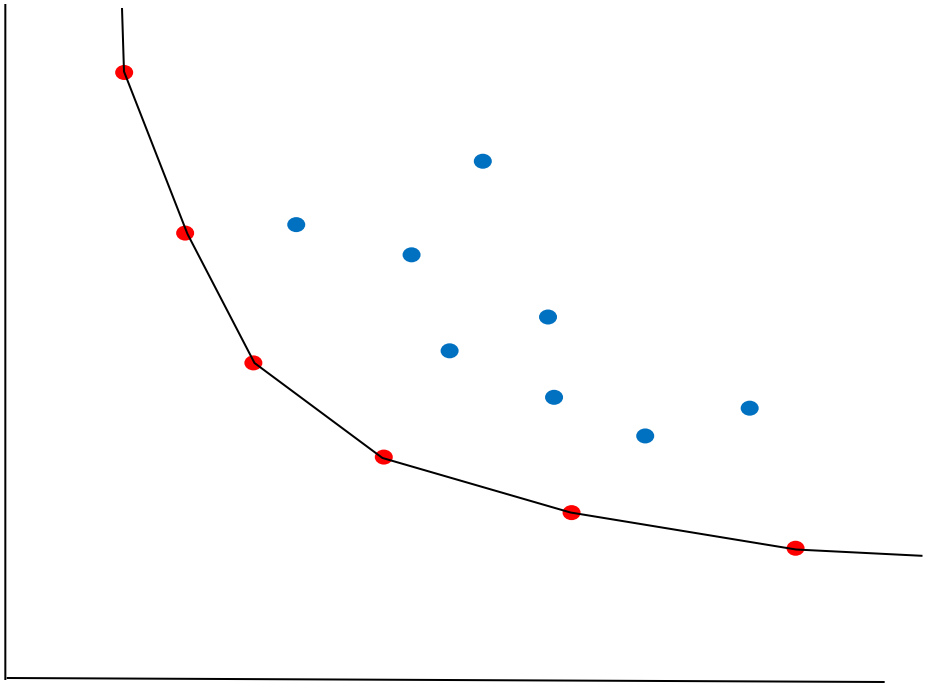
A measure of efficiency



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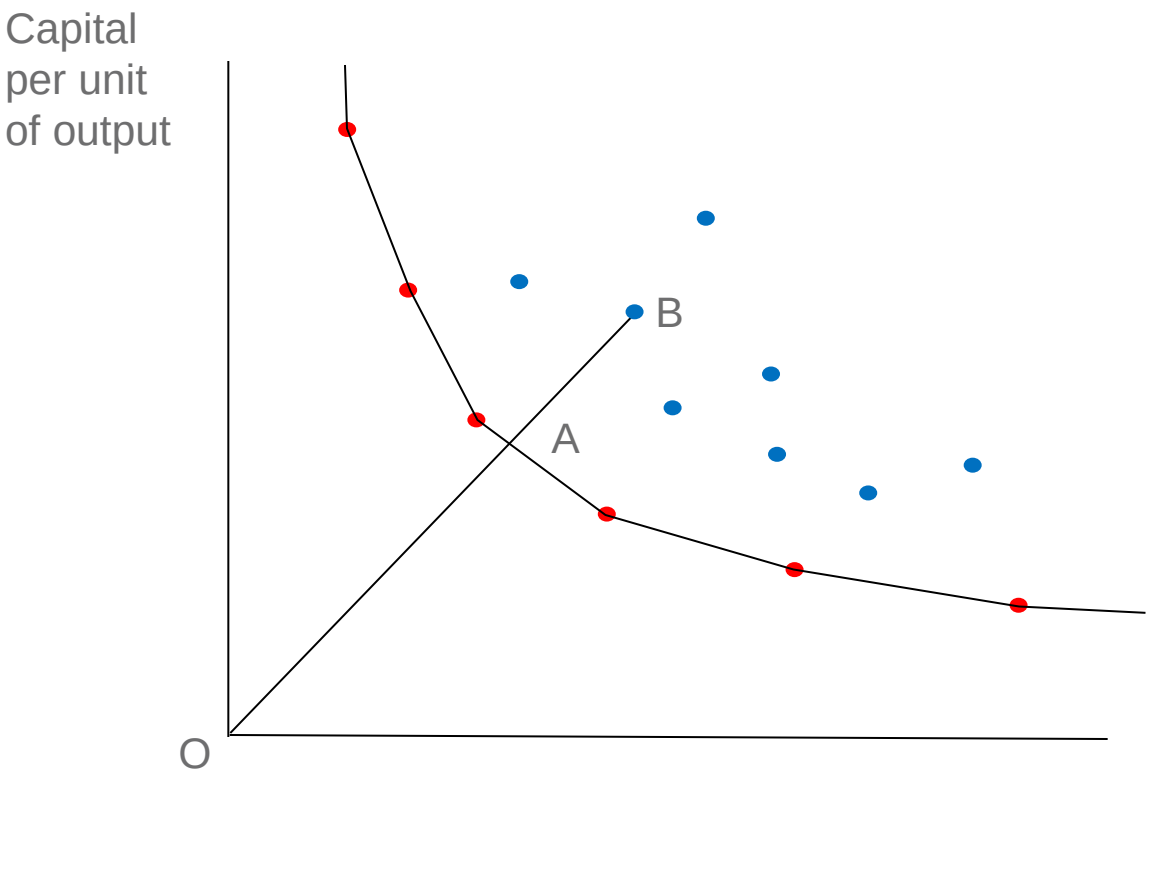
A measure of efficiency



Efficiency = OA/OB

Farrell,
(*Journal of the Royal Statistical Society*, 1957)

The efficient frontier

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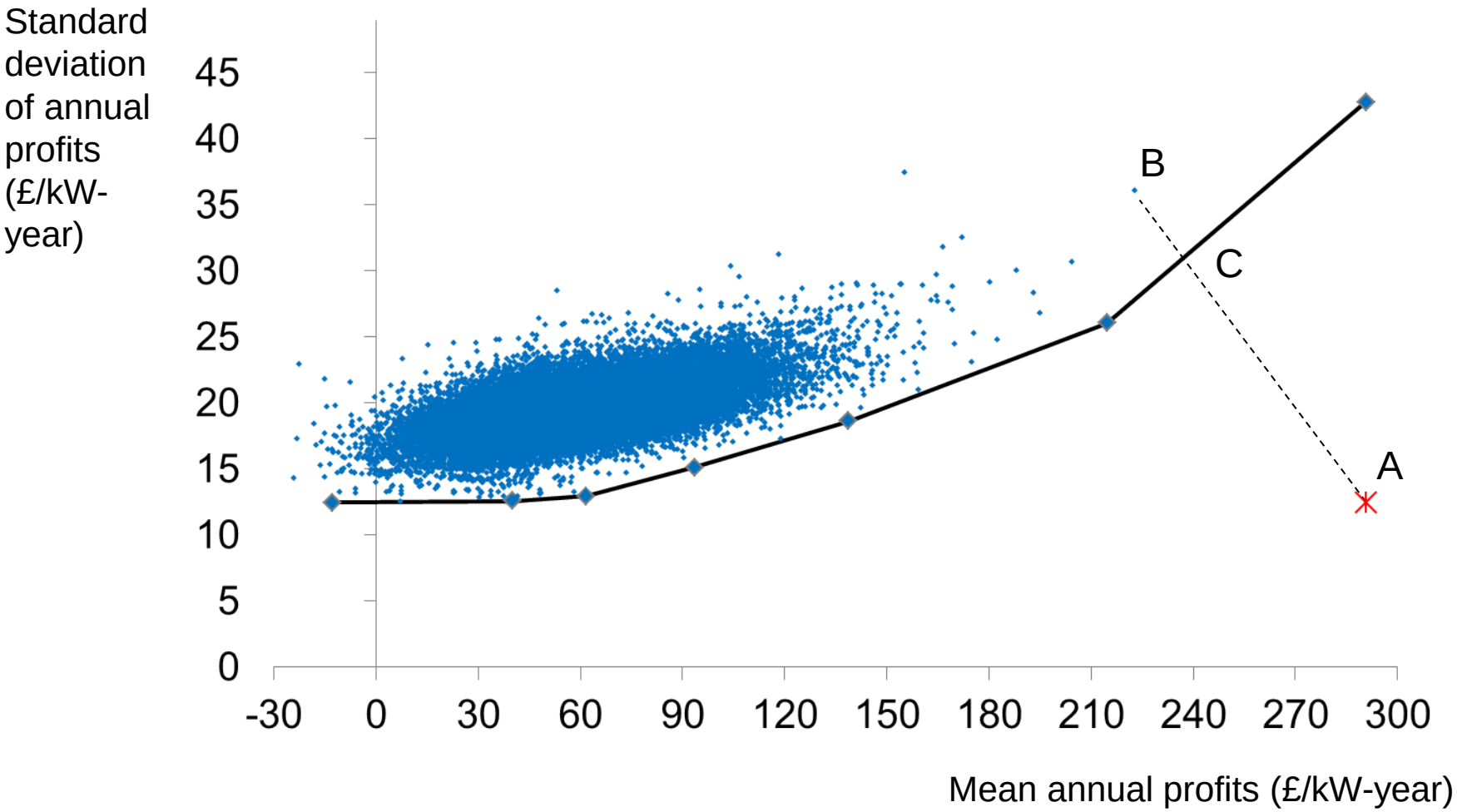
Measuring the efficiency of a portfolio



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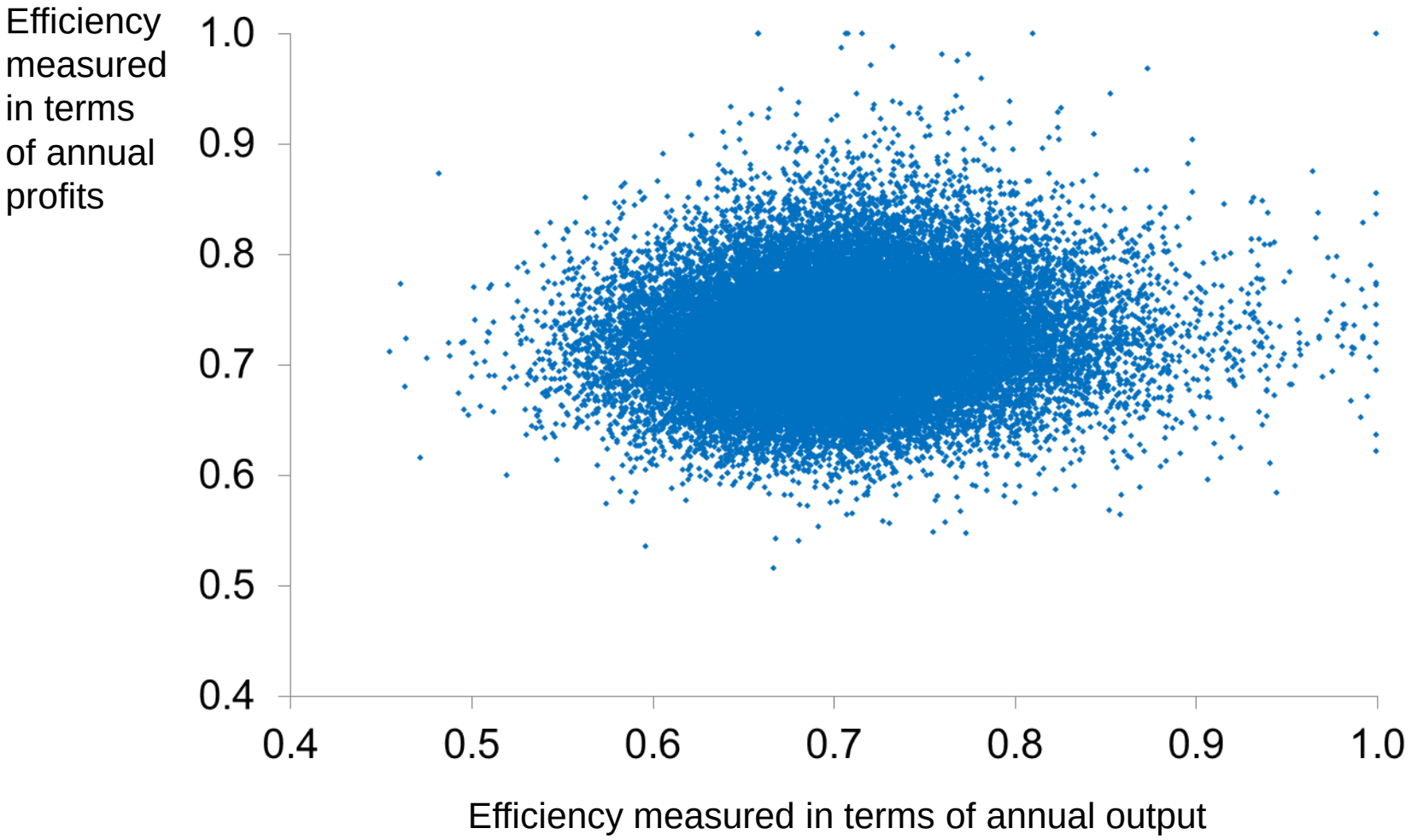
Is output efficiency informative?



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Conclusions

- Year-on-year changes in weather lead to economically important variations in wind farm profits
- A relatively small portfolio can dampen these
- Studying the mean-variance properties of a portfolio's output will not tell you much about its profits

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Extensions

- Study portfolios of on- and off-shore wind farms
- Weed out unprofitable farms from the model
- Consider a more sophisticated price-setting process

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