Uncertainty quantification in large scale energy systems models: GB exemplars

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UNCERTAINTY IN COMPUTER MODELS

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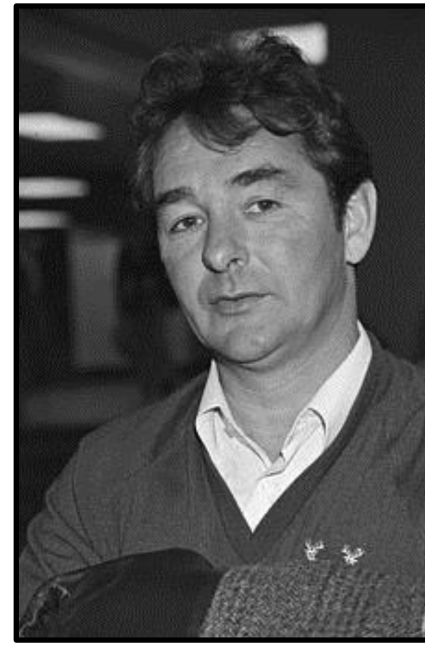
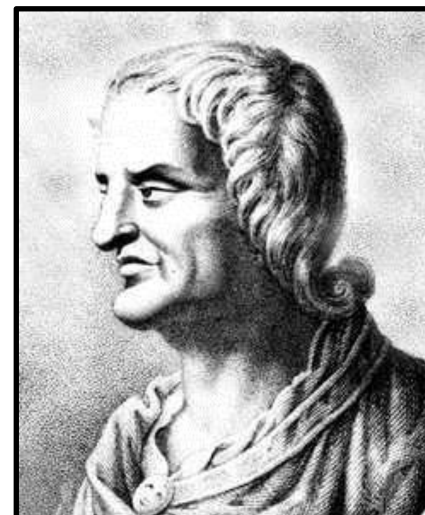
Uncertainty in modelling

- Some (more) well know quotations about modelling…
  - *All models are wrong, but some are useful* (George Box)
  - *False confidence* and *true confidence (Brian Clough)*
  - *Quis custodiet ipsos custodes* (Juvenal)
  - Physics community
  - *Never flinch, never weary, never despair* (Churchill)





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Classes of uncertainty in models

- Uncertainty – not being sure what model is saying about the world
- Parametric uncertainty: uncertainty about the appropriate input parameters to use
  - e.g. demand forecasts, investor risk level, weather data.
- Structural uncertainty: how the model structure relates to the real-world process it is modelling
  - e.g. is this process really Normally distributed? What effect does this simplifying assumption have on the results?
- Function uncertainty: what is output of the model at untested inputs

- All of these uncertainties can be found in both deterministic and stochastic simulators
  - e.g. in a model of security of supply risk, uncertainty in what the risk level is
  - Probability model ≠ "done uncertainty"!

Computer models

- A computer model
$$y = f(x)$$
  - x is input data and parameter choices
  - y is model outputs
- Finite number of evaluations of model possible
  - Value of x where y has not been evaluated matter
    - e.g. sensitivity analysis, integral over x in decision analysis
  - *Emulator* $\tilde{f}(x)$ of full model encodes uncertainty in $f(x)$ at x where model has not been evaluated (*some* knowledge)
  - Encodes all knowledge of f
- Linked to the world – uncertainty in…
  - … model inputs and parameters x
  - … how y represents real world quantities
  - … how f represents real word processes

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Why does this matter?

- Avoid overconfidence in results
  - What does ‘10’ mean?
- Normally want to reduce our uncertainty about the real world, not about the model
  - Need to model structural discrepancy
- Huge costs at stake in policy decisions
  - Cost of uncertainty analysis << cost of bad decision
  - Up front analysis often seen as “real cost” in comparison to consequences

- A note about emulation
  - Quantifying uncertainty in model outputs, and their relationship with the world, is a key part of making a logical argument
  - Emulation enables this when inputs are uncertain
  - Not an end in itself, but often requires much effort (inc methodology)
  - Vital point is having a logical argument

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EXEMPLAR – RENEWABLES SUPPORT SCHEME STRIKE PRICE

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Introduction to exemplar

- EMR – auctions for support for renewable technologies
  - Renewable generation guaranteed fixed price for energy (CFD strike price)
  - Generators make offers in competitive auction
  - *Administrative strike price* – cap for each future year
  - First auction was held in late 2014, with results in February 2015

<u>Administrative Strike prices</u>

The administrative strike prices applicable to applications in this allocation round are:

Table 2: Strike Prices

	CFD Strike Prices (£/MWh, 2012 prices)				
Technology	**2014/15**	**2015/16**	**2016/17**	**2017/18**	**2018/19**
Advanced Conversion Technologies (with or without CHP)	155	155	150	140	140
Anaerobic Digestion (with or without CHP) (>5MW)	150	150	150	140	140
Biomass Conversion	105	105	105	105	105
Dedicated Biomass (with CHP)	125	125	125	125	125
Energy from Waste (with CHP)	80	80	80	80	80
Geothermal (with or without CHP)	145	145	145	140	140

https://www.gov.uk/government/publications/cfd-budget-notice

The Dynamic Dispatch Model (DDM)

- DDM used to help determine the parameters of the auction
- Administrative strike prices that would result in
  - a total cost in 2020 of less than $7.6bn
  - a proportion of renewable generation greater than 30% in 2020
  - emissions of less than 100 gC02/kWh in 2030

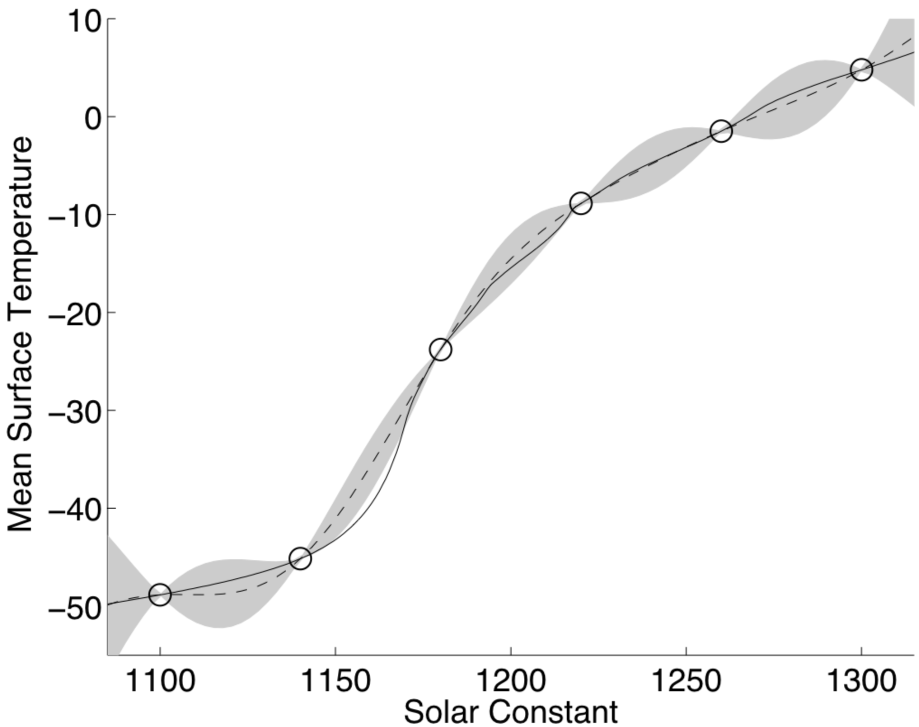
- Challenges
  - Computationally expensive (~1h per run)
  - Very high dimensional
  - Very sparse data for training emulator – key methodological point

Form of emulator - general

- Standard structure used widely

$$\tilde{f}(x) = \sum_i \beta_i h_i(\mathbf{x}) + \epsilon(\mathbf{x})$$

  - h_i basis functions (combinations of model inputs $\mathbf{x}$)
  - $\epsilon(\mathbf{x})$ typically a Gaussian process
    - for inputs $\mathbf{x}_1, \ldots, \mathbf{x}_m$ assumed that $\epsilon(\mathbf{x}_1), \ldots, \epsilon(\mathbf{x}_m)$ are MVN



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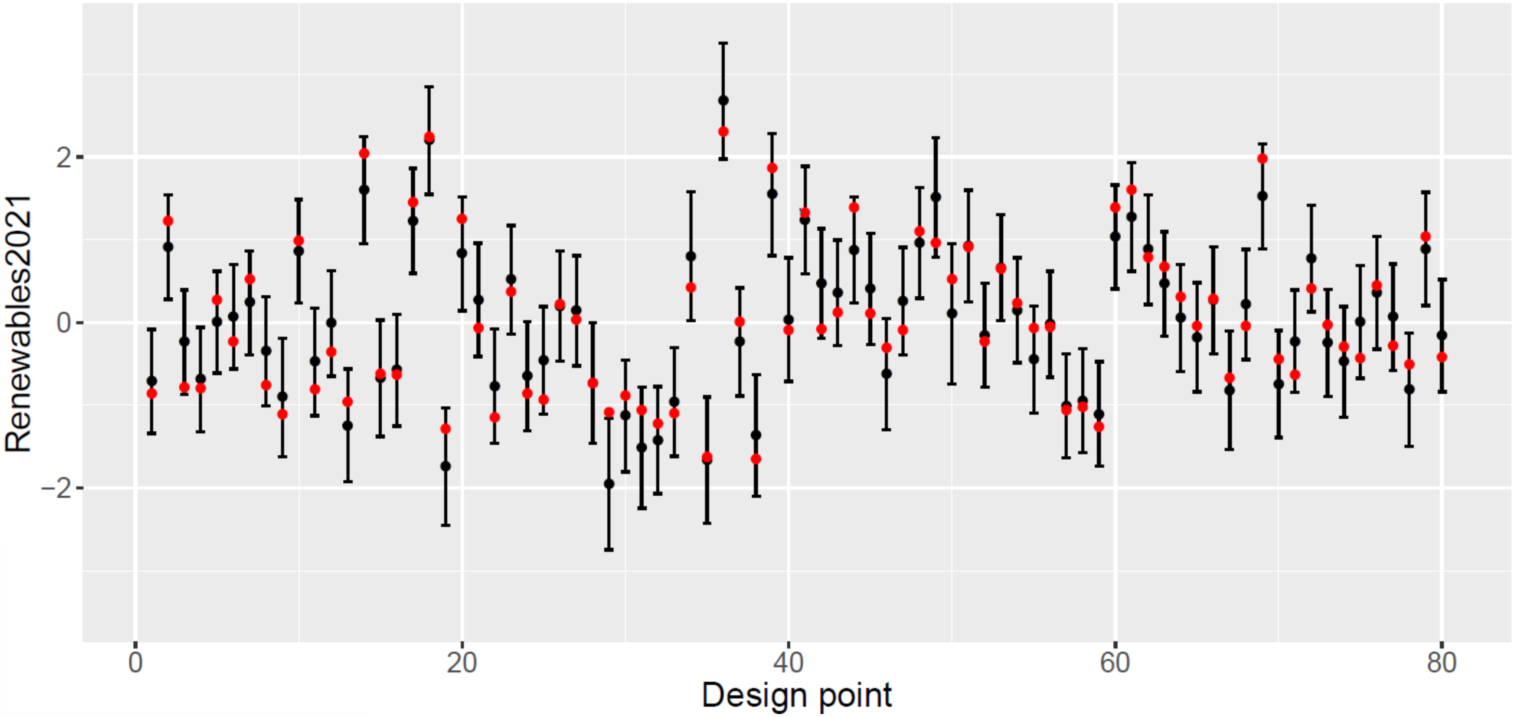
Form of emulator – this exemplar

- Standard structure

$$\tilde{f}(x) = \sum_i \beta_i h_i(\mathbf{x}) + \epsilon(\mathbf{x})$$

  - Develop criterion for careful choice of runs – minimise function uncertainty in regions where spend, emissions low and renewables high
  - Allow parameters of GP error model to vary across input space



14 inputs (strike prices, costs, demand, load factors, hurdle rates, etc.

3 outputs (spend, % renewables, emissions)

Next steps

- Using emulator, can estimate probability that any given set of strike prices will meet the three criteria
  - (cost, % renewables, emissions)
- This probability considers
  - function uncertainty (i.e. due to sparse coverage of parameter space by model runs)
  - input uncertainty (integrated over uncertainty in demand, fuel prices, technology cost, hurdle rates and load factors)
  - structural discrepancy (used 10% as an example of representing this as equivalent parametric uncertainty)

CONCLUSIONS

Other work on energy systems

- Meng Xu
  - Projections of generation investment
  - Application to market design
  - Papers in SEGAN, PMAPS
- Antony Lawson
  - Network capital planning
  - Paper on single stage in SEGAN, work under development on multistage
- Centre for Energy Systems Integration (CESI)
  - Managing uncertainty arising from embedding simplified operations models in planning problems
  - Efficient computation for large scale planning and economic projection models
  - Edinburgh Engineering and Maths, Durham Maths
  - Opportunities for collaboration through CESI

Conclusions

- All applied modelling makes predictions about the world
  - In a broad sense of ‘predict’
  - Vital to have a logical argument for what is learnt about the world
  - ‘Insights’ should be about world
- Methodology issues
  - Multiple runs required
  - Limited number of runs possible – requires e.g. emulation
  - Very high dimensional models
- Practical issues
  - Different way of thinking – # runs versus system detail
  - Analysis costs more – but greater true confidence
  - Communication outside modelling community
  - Wide range of skills required