Linking energy systems models to real systems: model calibration and emulation

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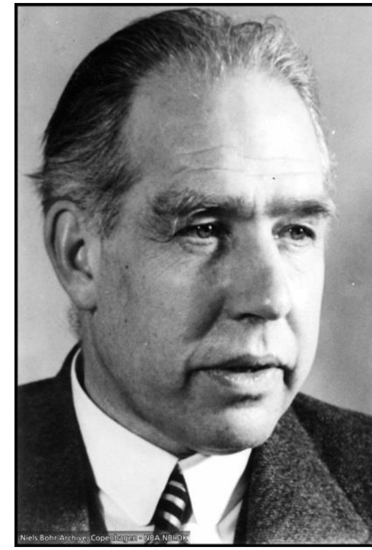
Uncertainty in modelling

- Some well know quotations about modelling…
  - *All models are wrong, but some are useful* (George Box)
  - *Simple models for insight, complex models for quantification* (Ben Hobbs)
  - *Prediction is very difficult, especially about the future* (Niels Bohr)
  - *Don't be too proud of this technological terror you've constructed* (Darth Vader to Death Star commander, Star Wars Episode IV)



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Contents

- Two key points
  - By statistical modelling I mean all aspects of quantitative management of uncertainty… not just inference from traditional data, and definitely not just point estimates of model outputs
  - We wish to take decisions based on our state of knowledge about the real world, not about our state of knowledge of computer model outputs

- Adequacy assessment – an example of relatively traditional statistical modelling
- How things are different when dealing with very complex computer models
- Examples from GB of uncertainty assessment in complex computer models
- Conclusions including technology transfer issues

EXAMPLE: ADEQUACY ASSESSMENT

Adequacy assessment: formulation

- Snapshot margin of available generating capacity over demand

$$Z = X + Y - D = M + Y$$

  - X, Y: available existing (conventional) and additional (wind) generating capacity, D: demand
  - Loss of Load Probability:

$$[\mathrm{LOLP}] = \mathrm{P}(Z < 0)$$

- Whole season index: *Loss of Load Expectation*

$$[\mathrm{LOLE}] = \sum_t [\mathrm{LOLP}]_t$$

- Capacity value: *Equivalent Firm Capacity (EFC)*
  - Completely reliable capacity which would give the same risk level if it replaced the stochastic resource Y

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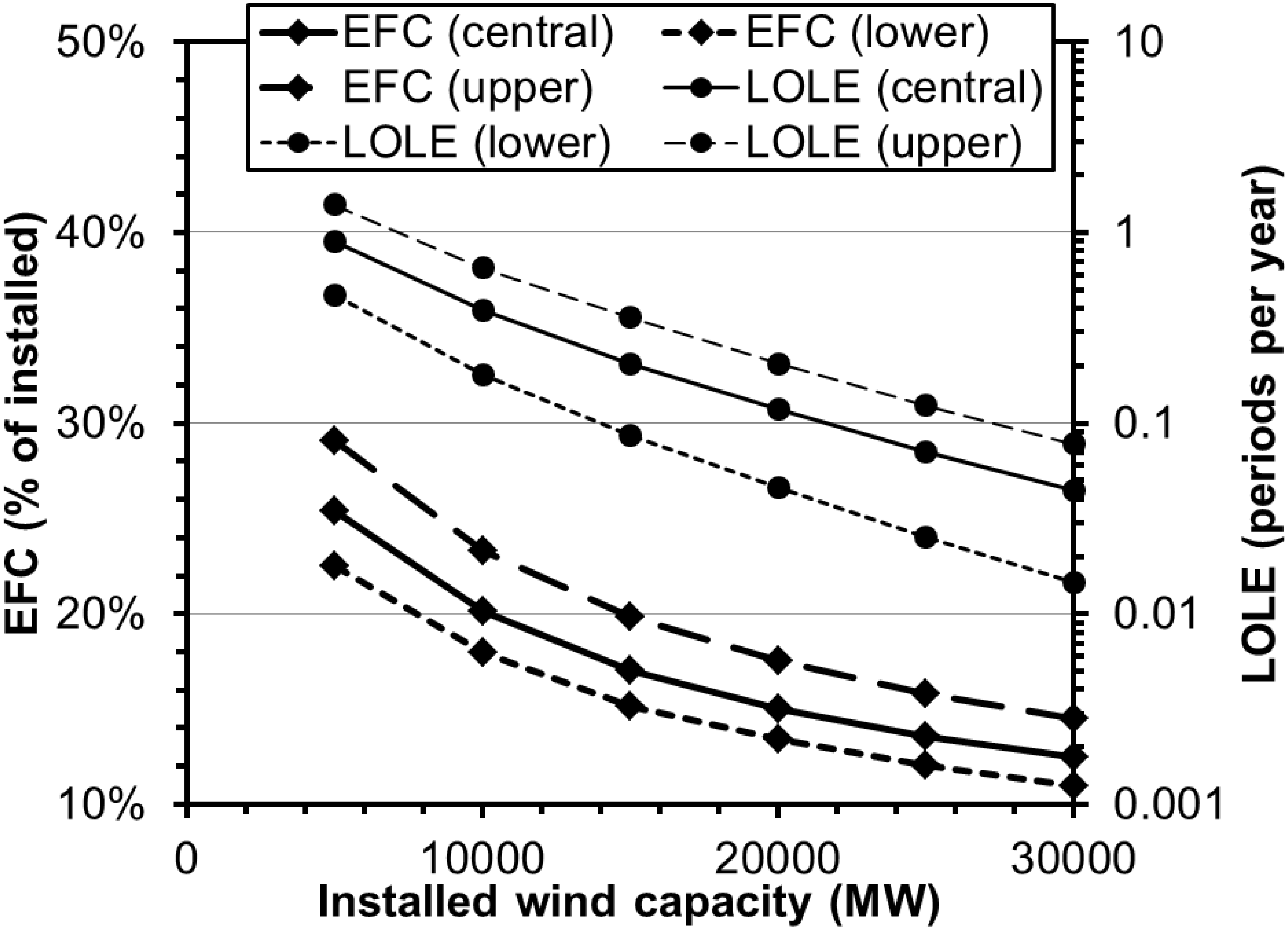
Results: hindcast



COMPLEX COMPUTER MODELS – GENERAL FORMULATION

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General formulation

- Typically we may regard a computer model as a function
$$y = f(x)$$
  - x is input data and parameter choices
  - y is model outputs
- Constraint costs (costs of required redispatch of generation due to finite network capacity)
  - x is network capacities, generation locations, availability properties and costs, demand profile, etc etc
  - y is constraint cost
- Generation investment
  - x is system background inc demand growth, fuel prices, possibly parameterisation of companies' decision criteria, etc etc
  - y is investment outcome, or perhaps adequacy risk
- However we are not sure what x should be
  - Nor whether, for a particular choice of x, f gets the consequences right – and for complex models we only know f for small no. of choices of x

Emulators

- Full computer model

$$y = f(x)$$

- Emulator

$$\tilde{y} = \tilde{f}(x)$$

  - Encodes our state of knowledge about y for each x: y only known precisely for values of x at which we have evaluated f
  - Elsewhere uncertainty in y represented as a probability distribution, i.e. $\tilde{f}(x)$ is a random variable
    - e.g. mean of $\tilde{f}(x)$ is an interpolator between evaluations of f
    - SD of $\tilde{f}(x)$ quantifies our uncertainty in f for values of x at which we have not evaluated
    - Covariance between $\tilde{f}(x)$ and $\tilde{f}(x')$ encodes how much an evaluation of f at x' is telling us about $f(x)$
- Constructing emulator is a statistical inference / estimation problem
  - Update emulator of faster model using limited # runs of full model
  - Alternate narrowing region of interest with improving emulator based on runs in region of interest

Sources of uncertainty (MG)

- Parametric uncertainty (each model requires a, typically high dimensional, parametric specification)
- Condition uncertainty (uncertainty as to boundary conditions, initial conditions, and forcing functions)
- ***Functional uncertainty (model evaluations take a long time, so the function is unknown almost everywhere)***
- Stochastic uncertainty (either the model is stochastic, or it should be)
- ***Solution uncertainty (as the system equations can only be solved to some necessary level of approximation)***
- ***Structural uncertainty (the model only approximates the physical system)***
- Measurement uncertainty (as the model is calibrated against system data all of which is measured with error)
- ***Multi-model uncertainty (usually we have not one but many models related to the physical system)***
- ***Decision uncertainty (to use the model to influence real world outcomes, we need to relate things in the world that we can influence to inputs to the simulator and through outputs to actual impacts. These links are uncertain.)***

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COMPLEX COMPUTER MODELS – GB EXAMPLES

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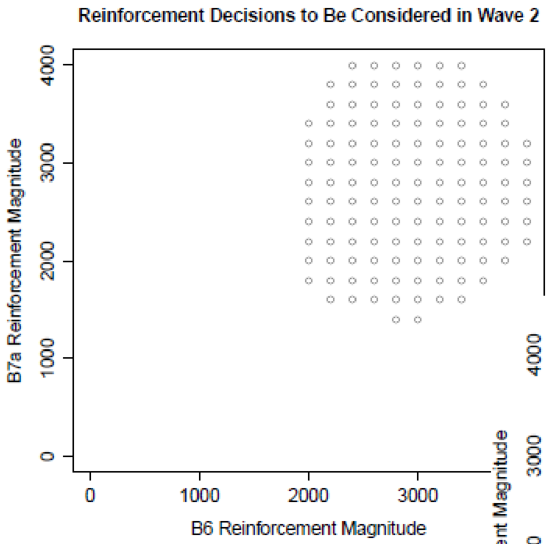
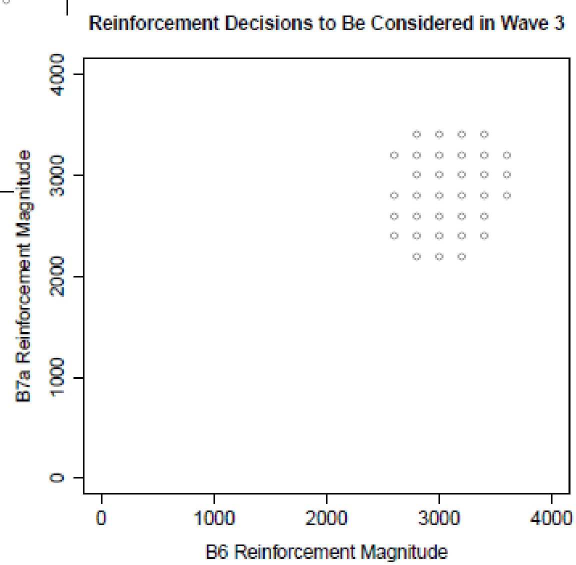
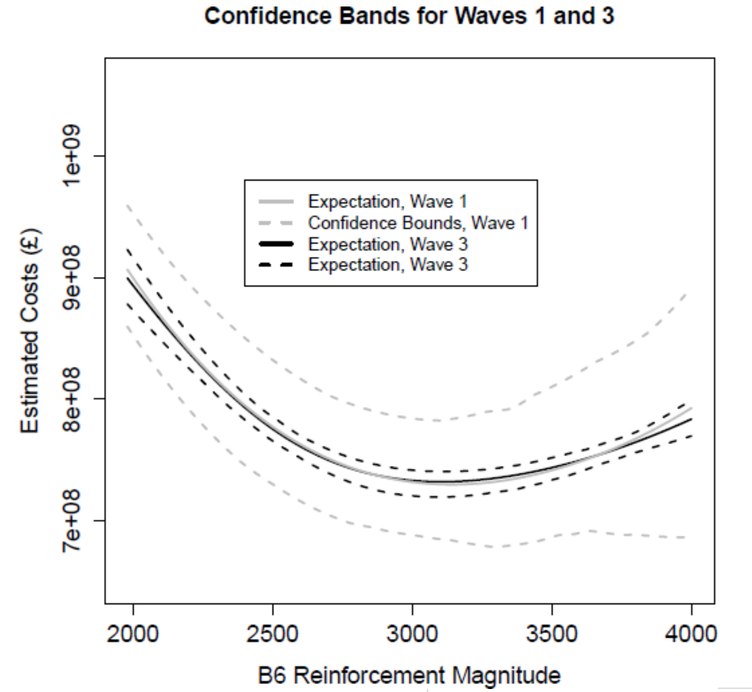
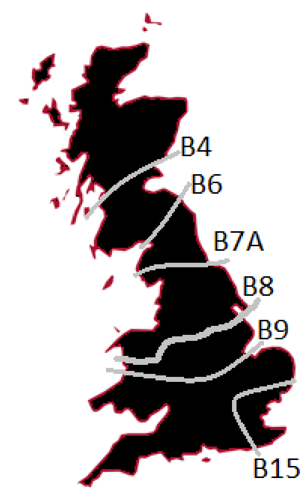
Transmission system planning









- Initially explore full range of possible reinforcements on two boundaries in GB system (with emulation)
  - Quantify uncertainty in model inputs
  - Narrow down, sample more densely (waves)
  - Introduce risk aversion

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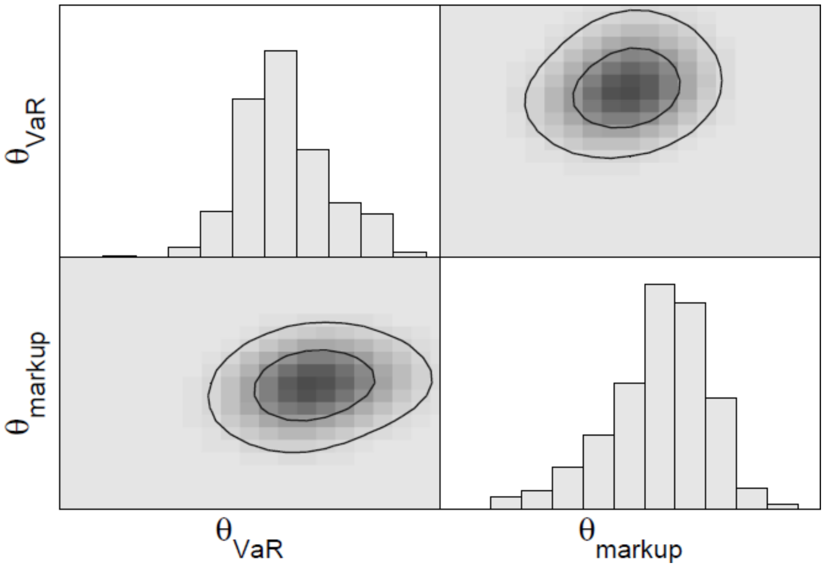
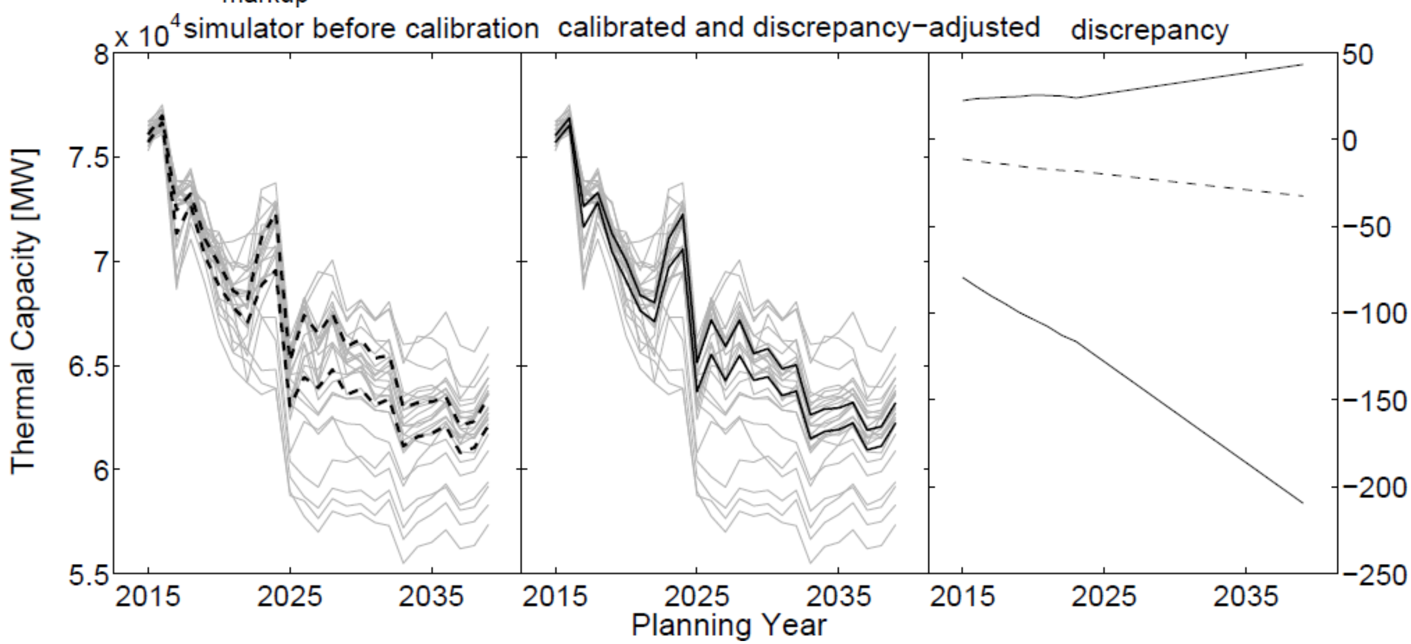
Generation investment projection



- Class of model heavily used in EMR
  - Example of calibration of simple model (after Eager et al)
  - Requires emulation due to substantial run time
  - Current work with DECC/NG on model of full complexity, V high dimensional inputs



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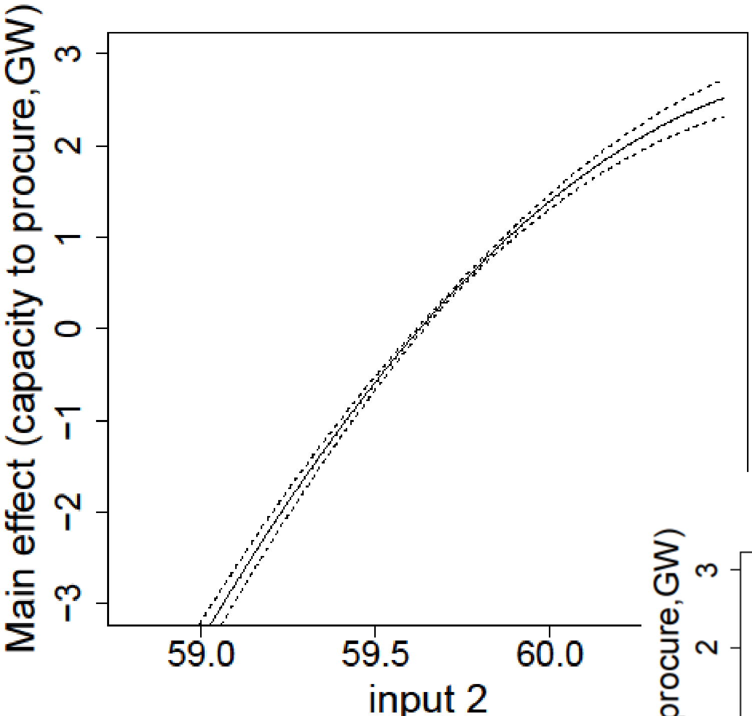
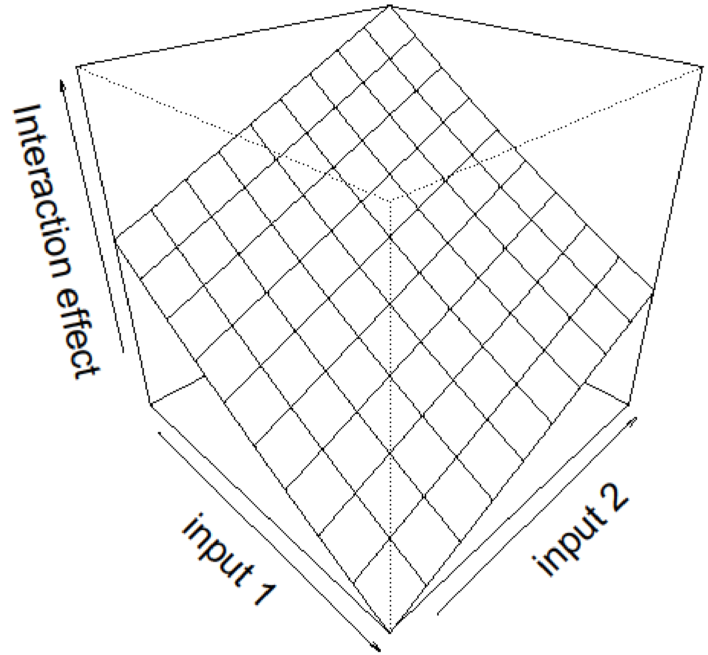
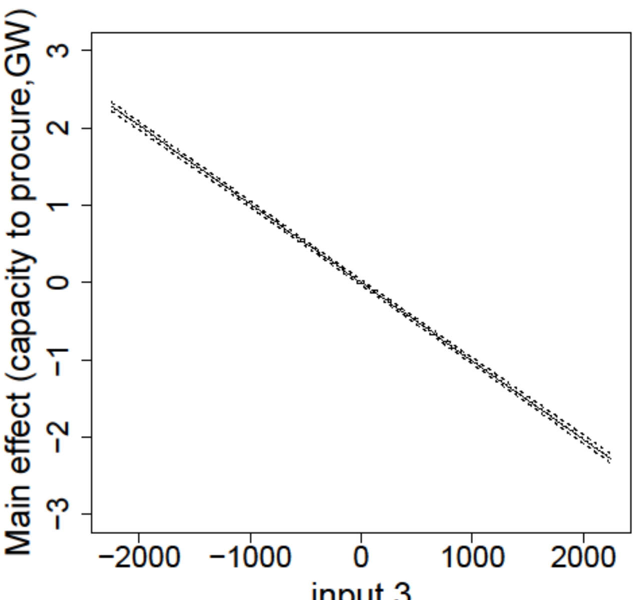
Policy application







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Conclusions

- Computer models widely used in energy systems modelling
  - Whole energy system models (V high dimensional inputs)
  - Energy systems impacts of climate
- Doing this well means…
  - Carefully relating the model (structure and inputs) to the real system
  - Bringing together right combinations of researchers (engineering, mathematical sciences, meteorology, social sciences etc)
- Important issues in technology transfer
  - Greater uncertainty and complexity requires new analytical approaches (in energy system context)
  - These are not just academic toys – they are needed to solve practical ops and planning problems which we face now
  - How to transfer new approaches into industry practice when relevant skills are not widespread in engineering companies?