Climate Forecasting with Chaos, or Chaos in Climate Forecasting?

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The Problem

Making decisions about provisions for the future:

- flood walls, water provision, etc. (adaptation),
- implementing changes and ideally stop bad things from happening (mitigation).

It's *not* establishing whether climate change is real! There is plenty of solid evidence that it is!

Response: build a model of the world's climate taking all relevant factors into account, predict what the future will be like, and then decide what to do about it.

In other words, do what physics has always done (and has done well).

Problem: Things are not that easy …

Preview

Concretely: Climate models

Abstractly: Non-linear models with *model error*

So far non-linearity ("chaos") has been studied in connection with uncertainty about *initial conditions*; we ask what happen if we are uncertain about the correct ***model structure.***

Take home message:

If non-linear systems have even the slightest ***model error***, their capacity to make meaningful (and policy relevant!) probabilistic forecasts is lost.

Practical Importance: This casts serious doubt on the feasibility – and indeed desirability – of large scale projects like UKCP.

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Apologies to the practitioners: the conclusions is mainly negative.

Francis Bacon:

“Truth will sooner come out from *error* than from *confusion.*”

So clearing up confusion is a contribution to (potential) success!

Lead in:

- Climate Models de facto are non-linear.
- But they are very complicated and both computationally hard and costly to study.
- So we study a simple non-linear system as a ***proxy*** of large climate models: the logistic map.
- The claim is not that a real climate model has the exact algebraic structure of the logistic map; the claim is the problems described are *typical for non-linear systems,* and hence a fortiori for climate models.

Example: Population of Fish

Population ratio:

N_t = # fish in the pond at time t / # max number

Model:

$$N_{t+1} = 4 N_t(1- N_t)$$

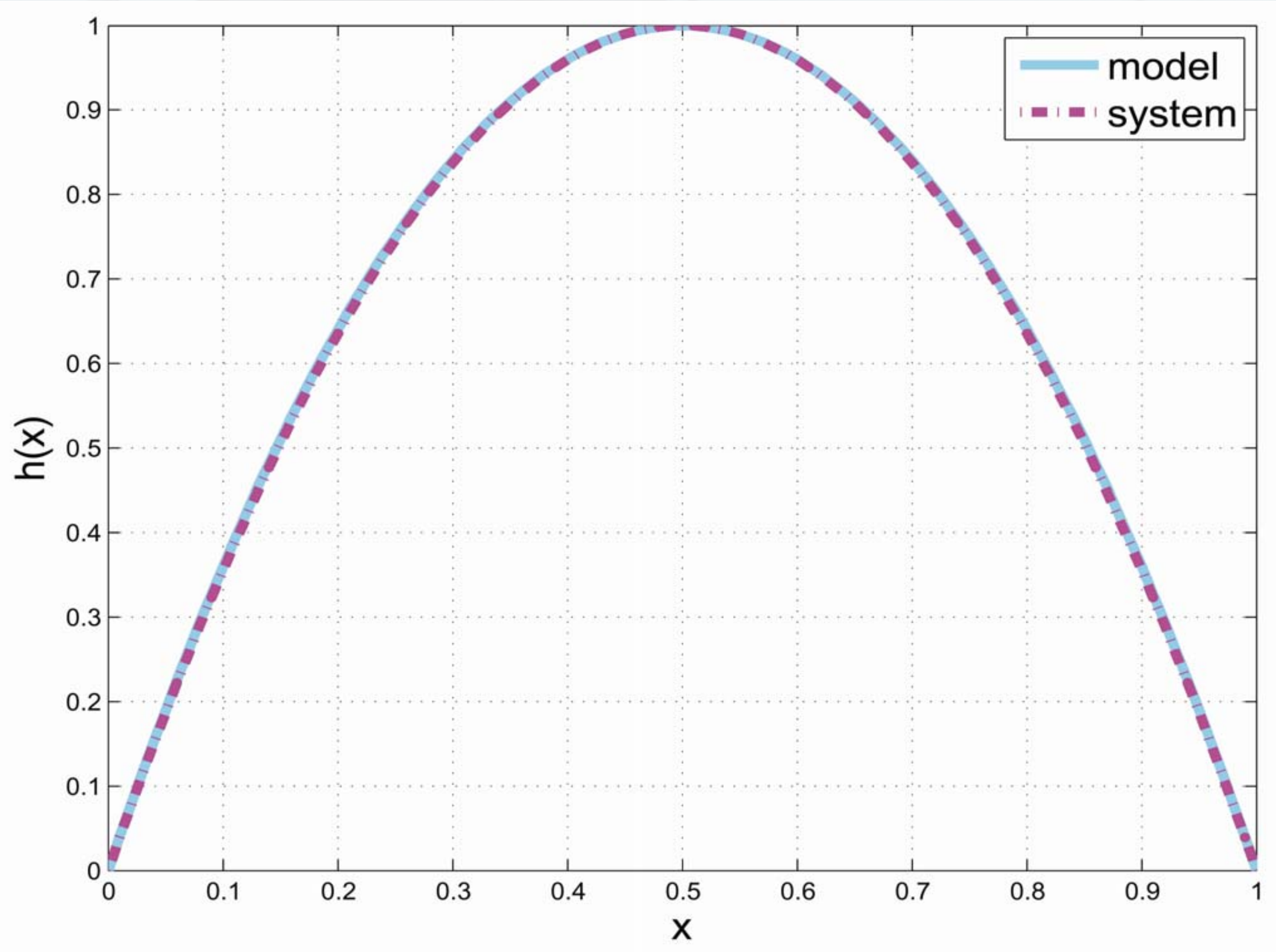
Logistic Map!

Thought experiment:

We have built a model for the population of fish and now God whispers into our ear what the real functional dependence is:

Model: $N_{t+1} = 4\, N_t(1 - N_t)$

World: $N_{t+1} = 4\, N_t(1 - N_t)$ **+ small perturbation**



ε = 0.1

One step error 1/1000.

So we got it almost right!

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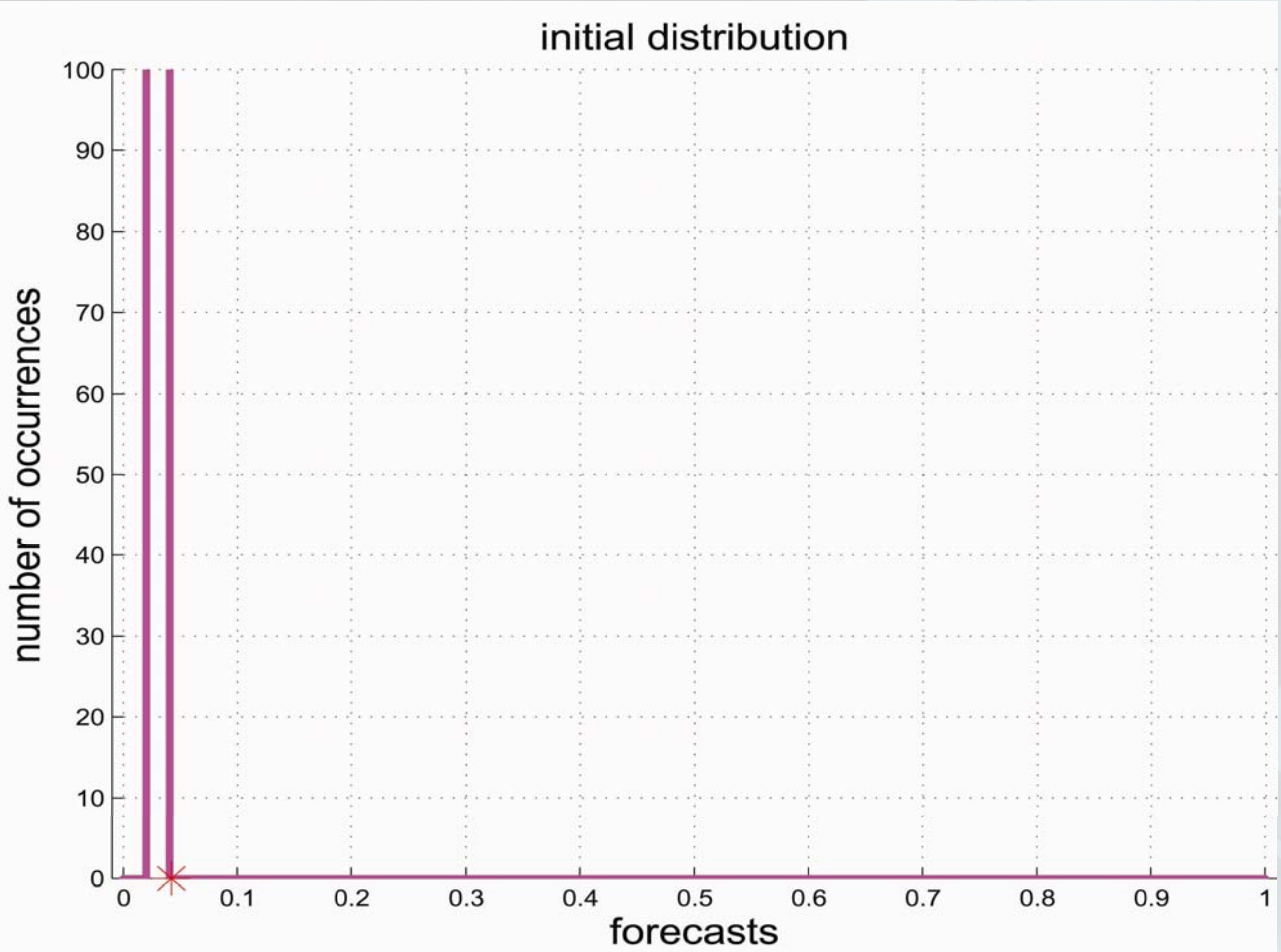
Wrong!

Probabilities:

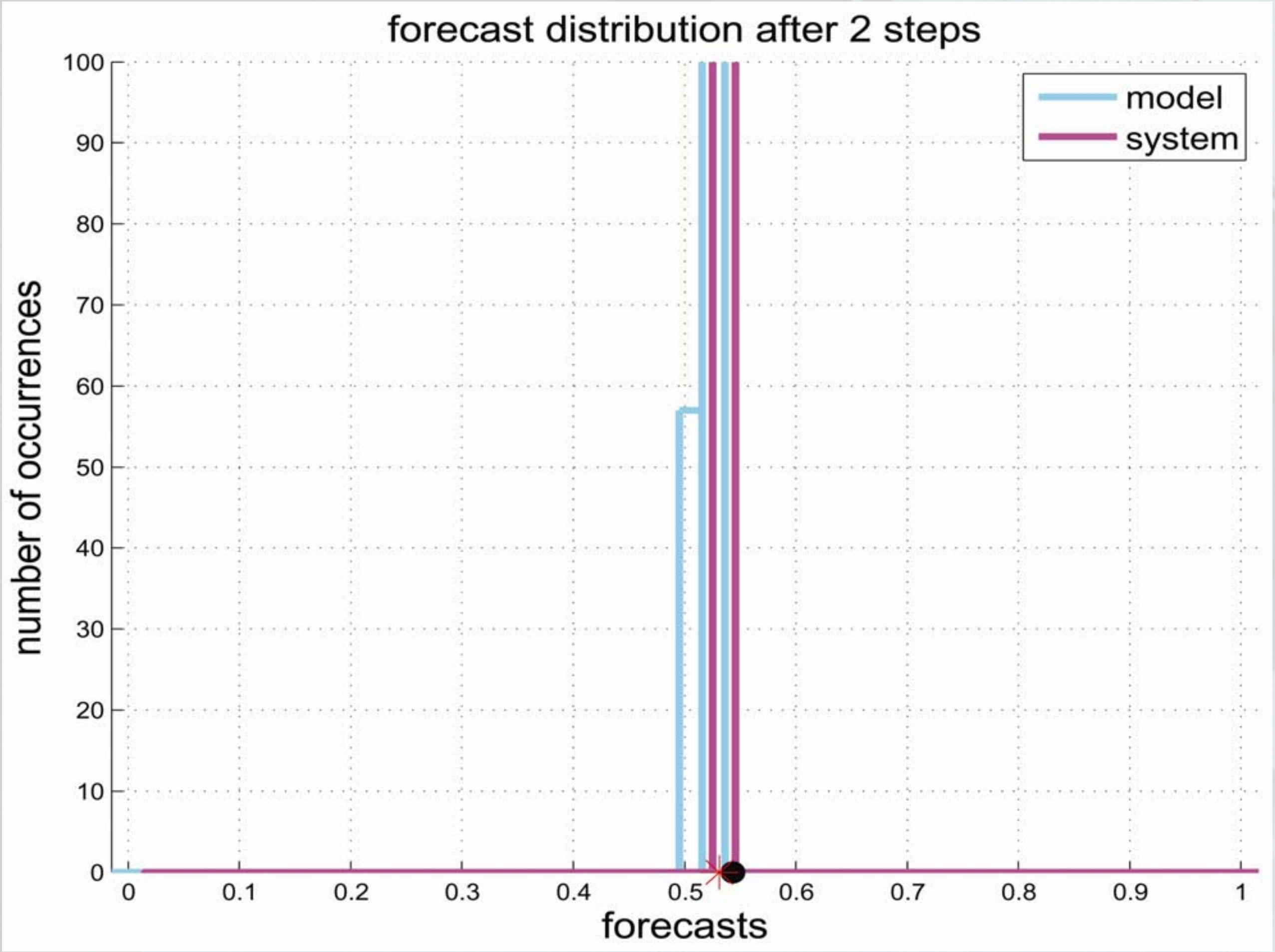
You don’t know the exact number of fish at time t, but you have estimate with some uncertainty → Probability distribution.

Question: how does the distribution move through time?

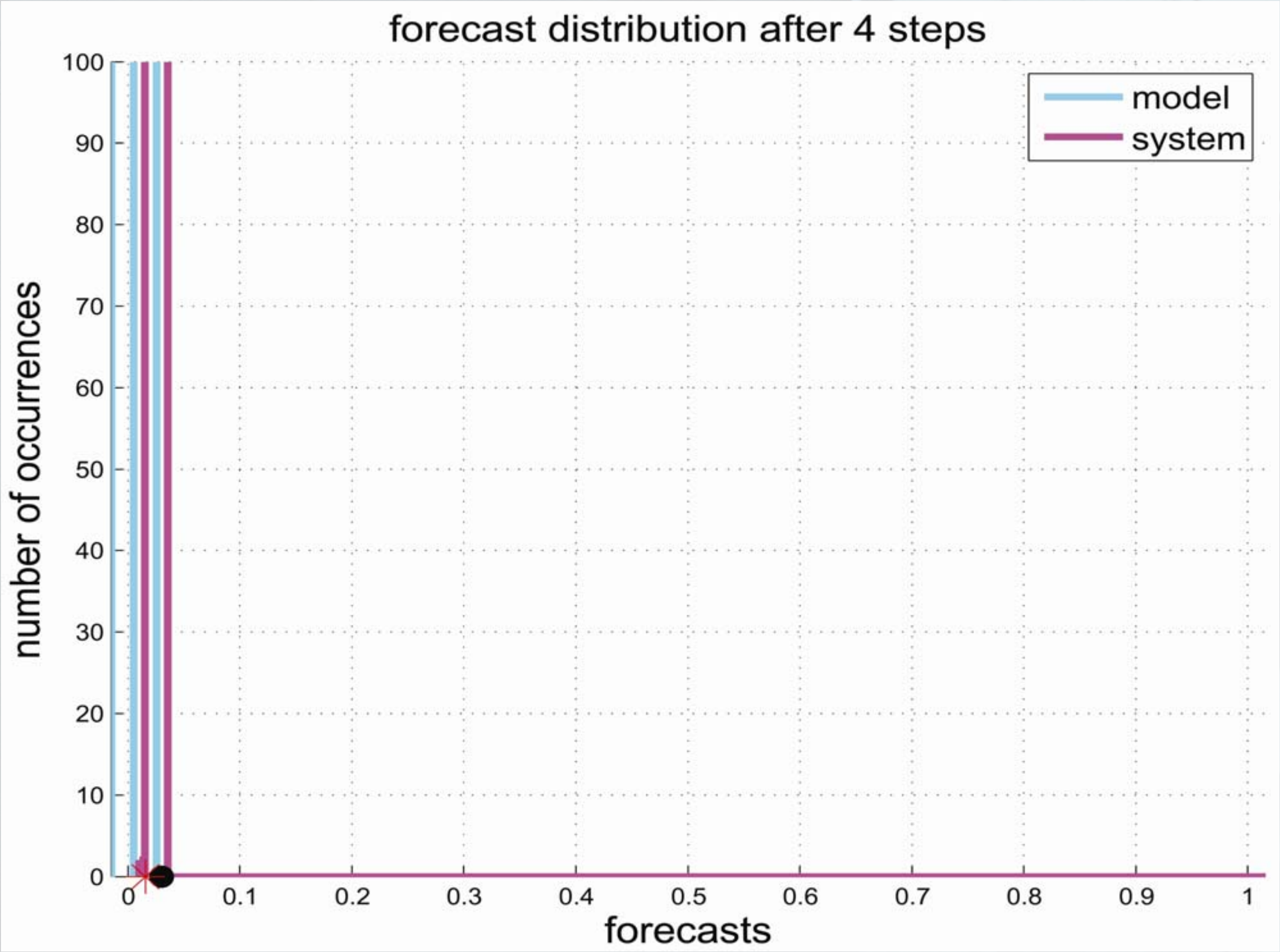
Initial Distribution



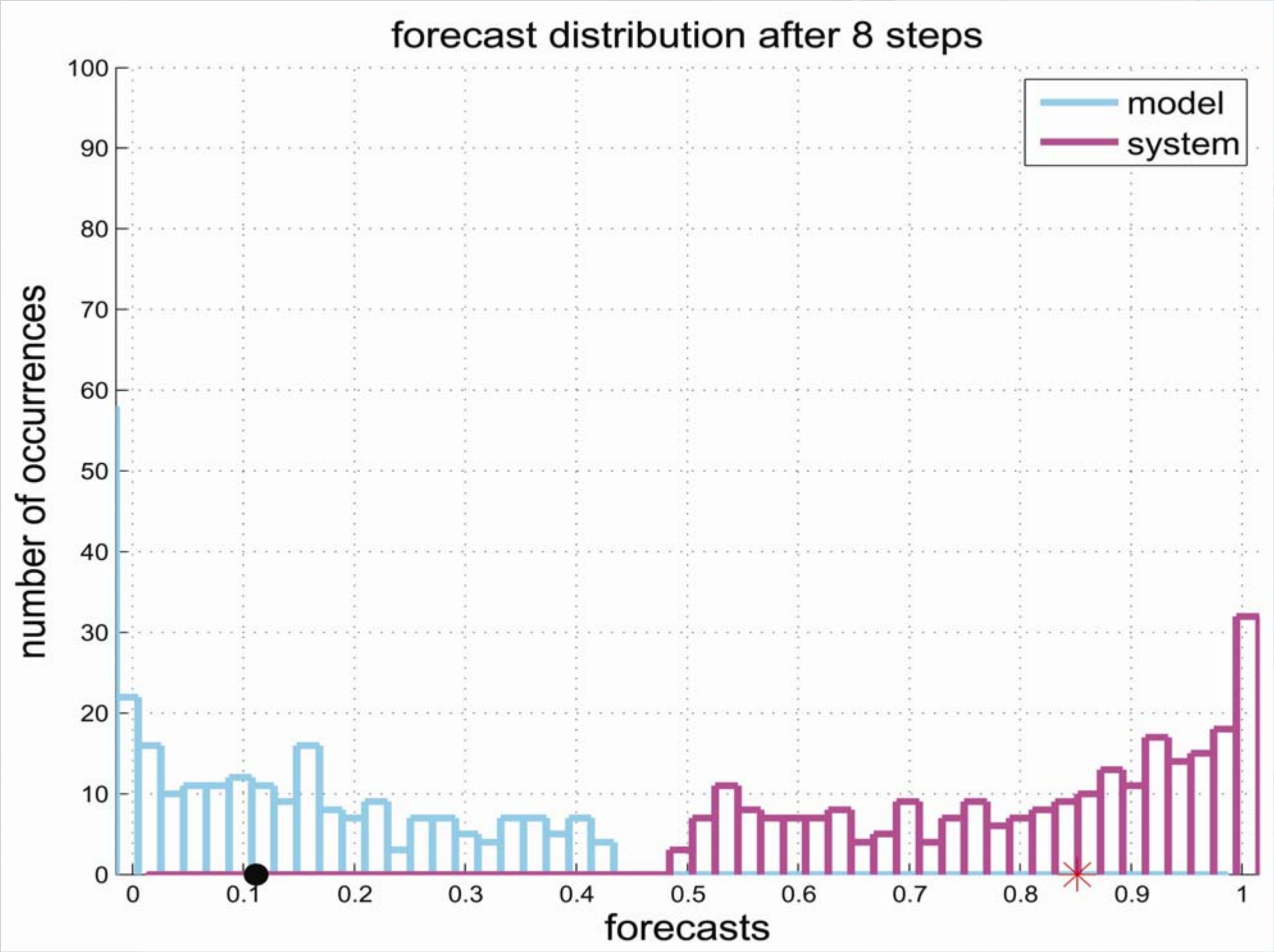
After 2 time steps:



After 4 time steps



After 8 time steps



This is not a special case!

Possible counter: you have cleverly chosen a special initial distribution for which things go wrong, but for most distributions predictions are fine.

No!

Relative entropy of two distributions is a measure for how different they are: the higher the entropy the more different the distributions.

Relative Entropy of 2048 initial distributions (t=8)

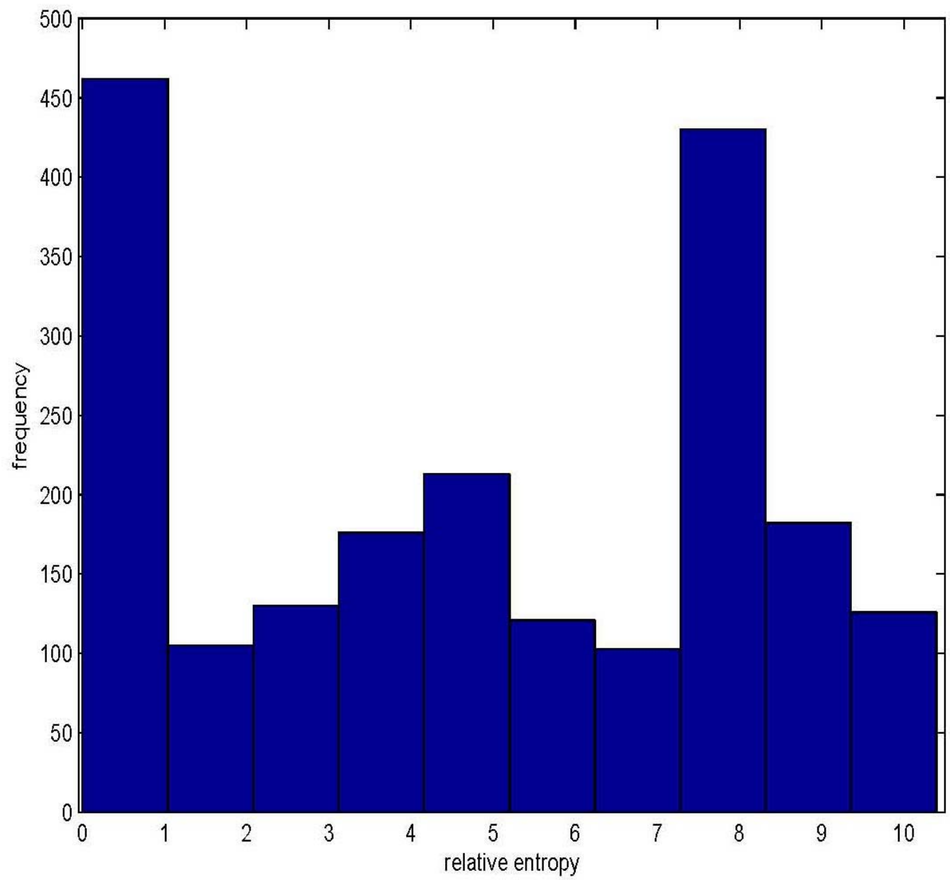


Figure 1: Histogram of relative entropy for 2048 forecasts at lead time 8

Practical consequence: Probabilist bookies go bust … even against really dumb punters

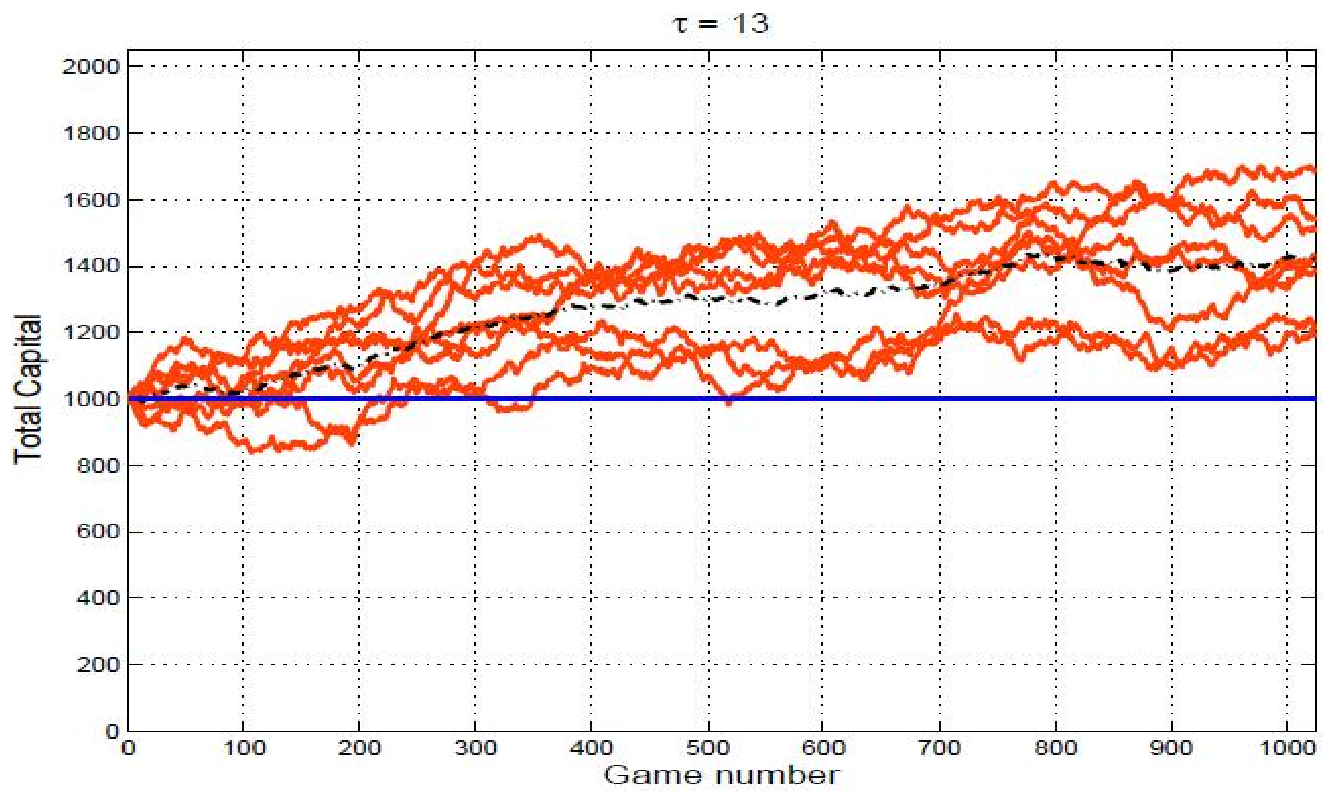


Figure 13: Time series of 8 punters' wealth when each repeatedly places unit bets on 16 possible events. Odds are placed by a bookie using the logistic model. The black line is the punters' average wealth against time. The blue horizonal line corresponds to no returns.

Criticisms (brief summary)

1. Bad proxy
2. Build a linear model instead
3. Climate models are effectively linear for relevant lead times
4. Descriptively indaquate
5. Quibbles about relevant time scales
6. Nothing special about non-linearity here

→ All these criticisms misfire and the argument stands

Conclusion

- Climate change **is** real.
- But the detailed/local effects of climate change are unpredictable – at least with the kind of models we currently have.
- So investing millions into ever larger models with the aim of detailed predictions (a la UKCP) is a waste of money.
- Sensible climate policy can be made without such models (cf. Dutch Policy).

Thank you!