

Forecasting the future and the future of forecasting

Professor Rob J Hyndman



robjhyndman.com/uncertain_futures

Outline

- 1 The dark history of forecasting
- 2 What can we forecast?
- 3 Forecasting PBS expenditure
- 4 Forecasting peak electricity demand
- 5 Forecasting COVID-19 cases
- 6 Assessing forecast uncertainty
- 7 The bright future of forecasting

Outline

- 1 The dark history of forecasting
- 2 What can we forecast?
- 3 Forecasting PBS expenditure
- 4 Forecasting peak electricity demand
- 5 Forecasting COVID-19 cases
- 6 Assessing forecast uncertainty
- 7 The bright future of forecasting

Forecasting by maggots



Clay model of sheep's liver

Used by Babylonian
forecasters approximately
600 B.C.

Now in British Museum.

Forecasting by hallucination



Forecasting by hallucination



Forecasting and the law

Anyone who consults a soothsayer on account of curiosity of the future will suffer capital punishment.

Codex Theodosianus 9.16.4



Reputations can be made and lost

“I think there is a world market for maybe five computers.”

(Chairman of IBM, 1943)

Reputations can be made and lost

“I think there is a world market for maybe five computers.”

(Chairman of IBM, 1943)

“There is no reason anyone would want a computer in their home.”

(President, DEC, 1977)

Reputations can be made and lost

“I think there is a world market for maybe five computers.”

(Chairman of IBM, 1943)

“There is no reason anyone would want a computer in their home.”

(President, DEC, 1977)

“There’s no chance that the iPhone is going to get any significant market share. No chance.”

(Steve Ballmer, CEO Microsoft, April 2007)

Reputations can be made and lost

“I think there is a world market for maybe five computers.”

(Chairman of IBM, 1943)

“There is no reason anyone would want a computer in their home.”

(President, DEC, 1977)

“There’s no chance that the iPhone is going to get any significant market share. No chance.”

(Steve Ballmer, CEO Microsoft, April 2007)

“We’re going to be opening relatively soon … The virus … will go away in April.”

(Donald Trump, February 2020)

What is a forecast?

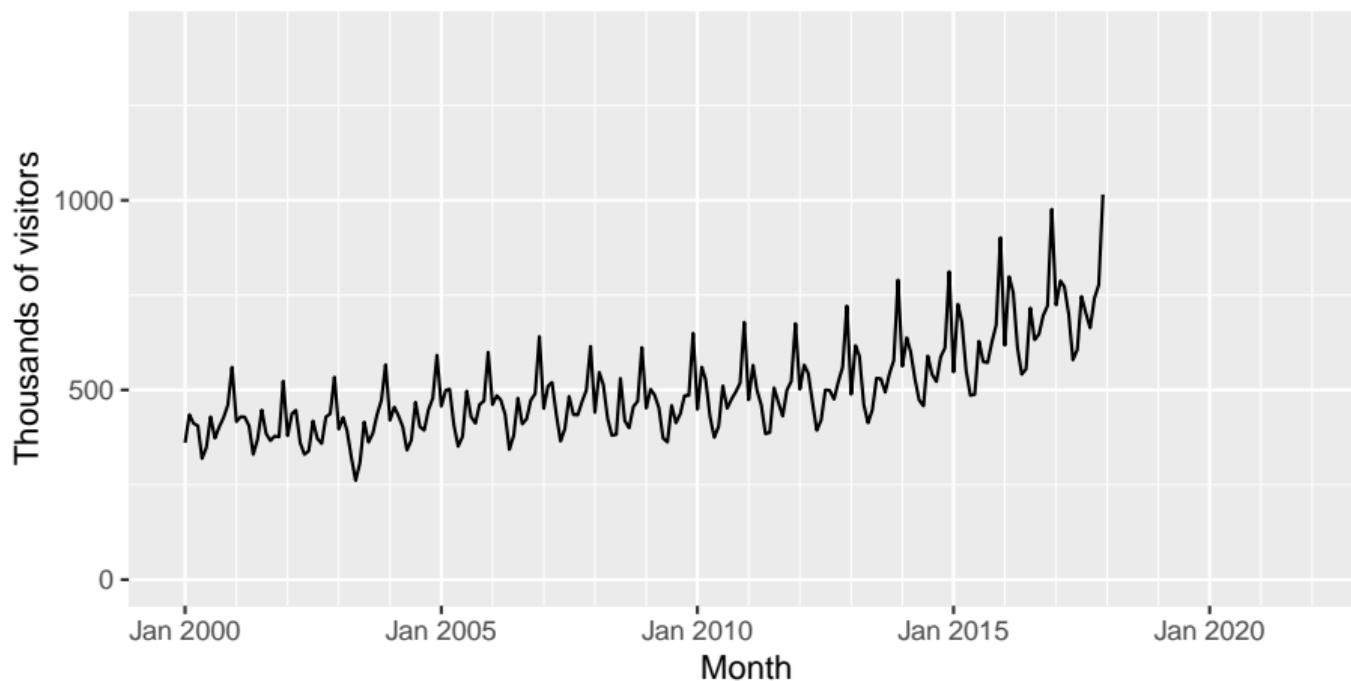
Random futures

A forecast is an estimate of the probability distribution of a variable to be observed in the future.

Random futures

A forecast is an estimate of the probability distribution of a variable to be observed in the future.

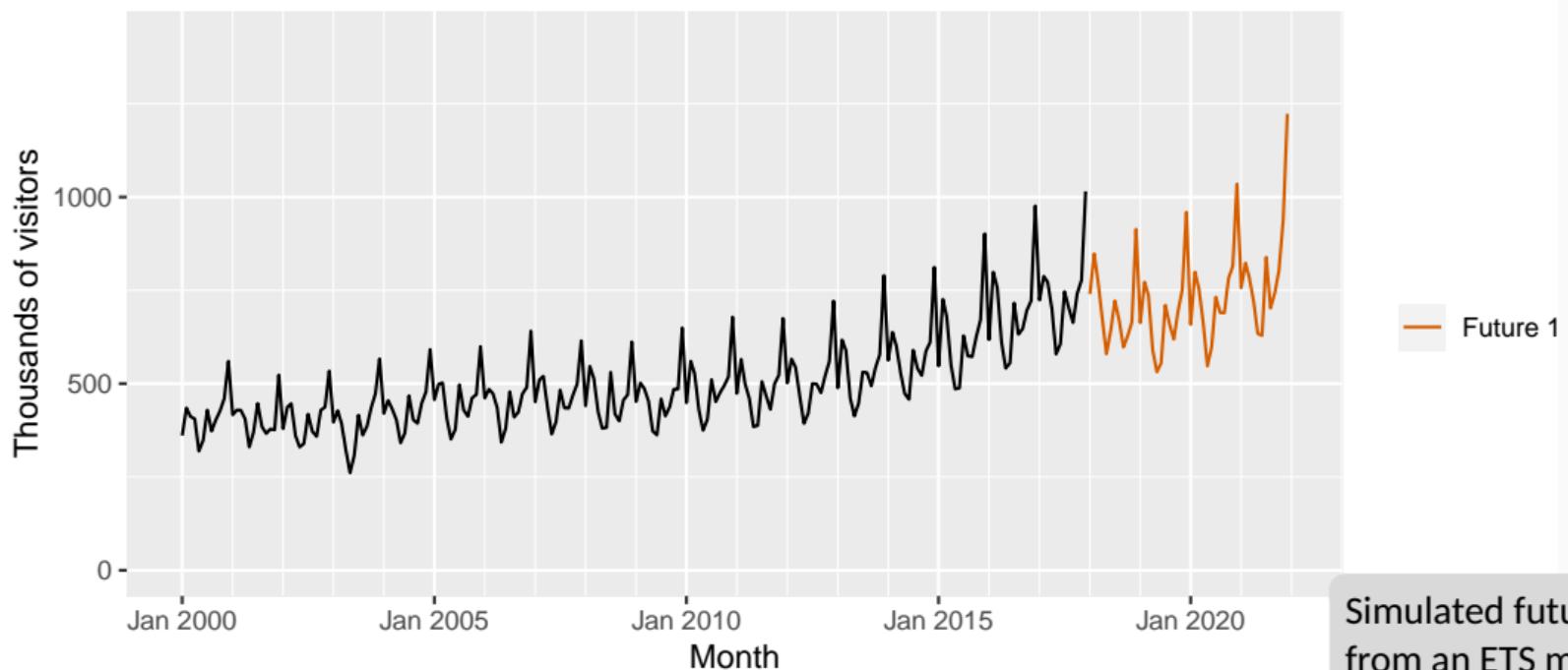
Total short-term visitors to Australia



Random futures

A forecast is an estimate of the probability distribution of a variable to be observed in the future.

Total short-term visitors to Australia

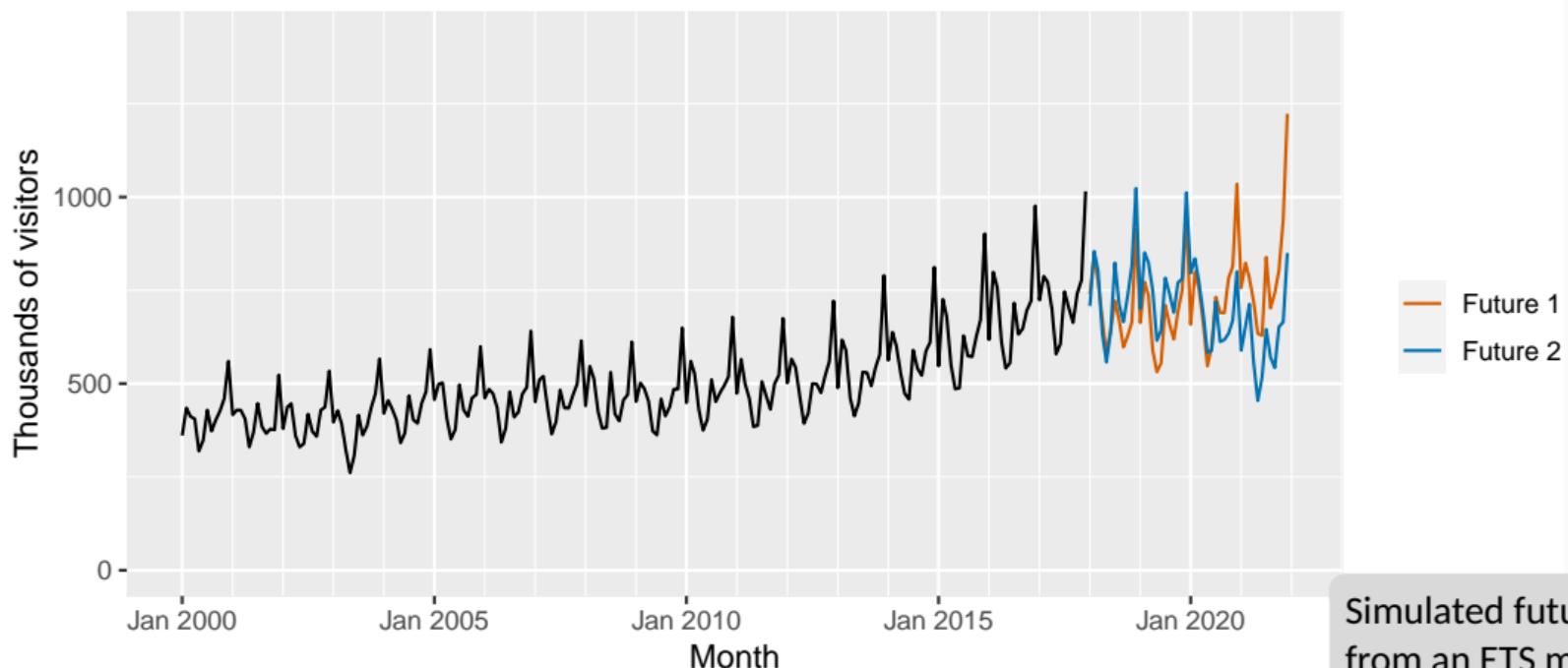


Simulated futures
from an ETS model

Random futures

A forecast is an estimate of the probability distribution of a variable to be observed in the future.

Total short-term visitors to Australia

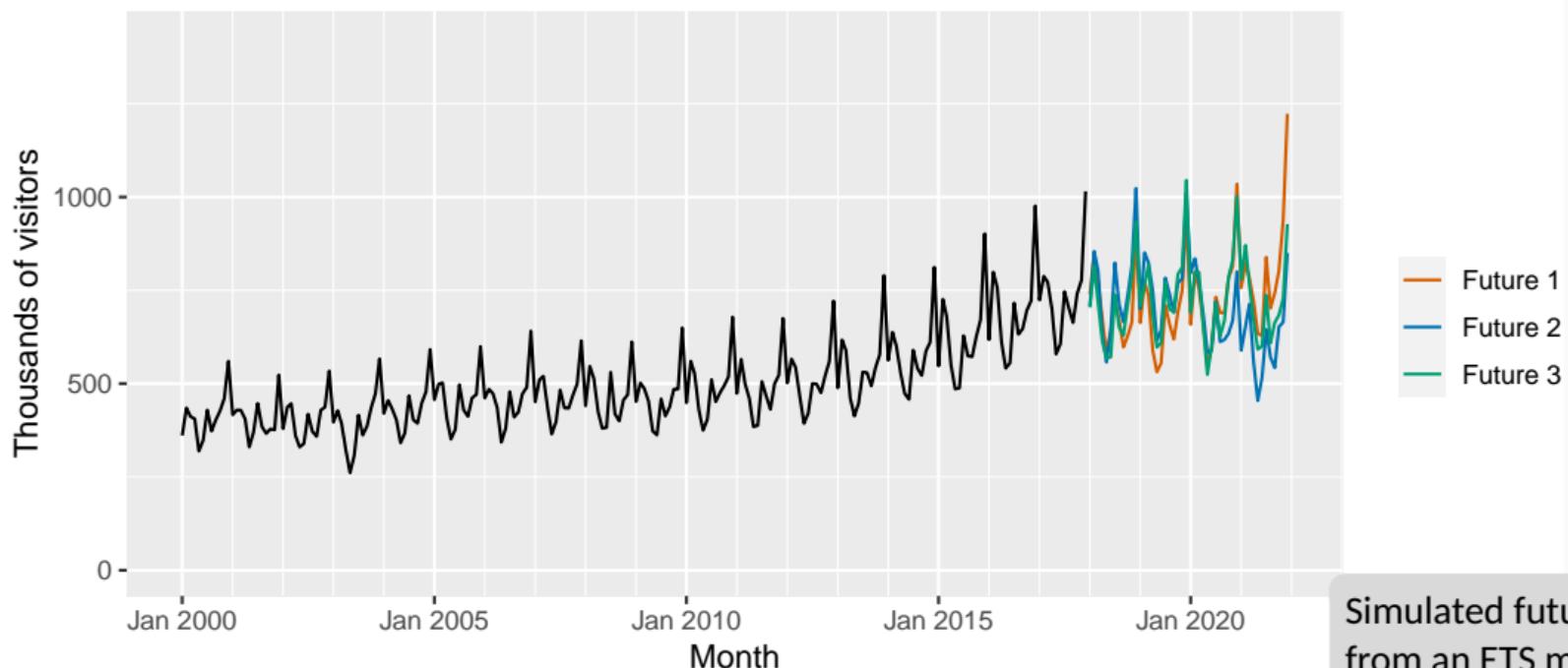


Simulated futures
from an ETS model

Random futures

A forecast is an estimate of the probability distribution of a variable to be observed in the future.

Total short-term visitors to Australia

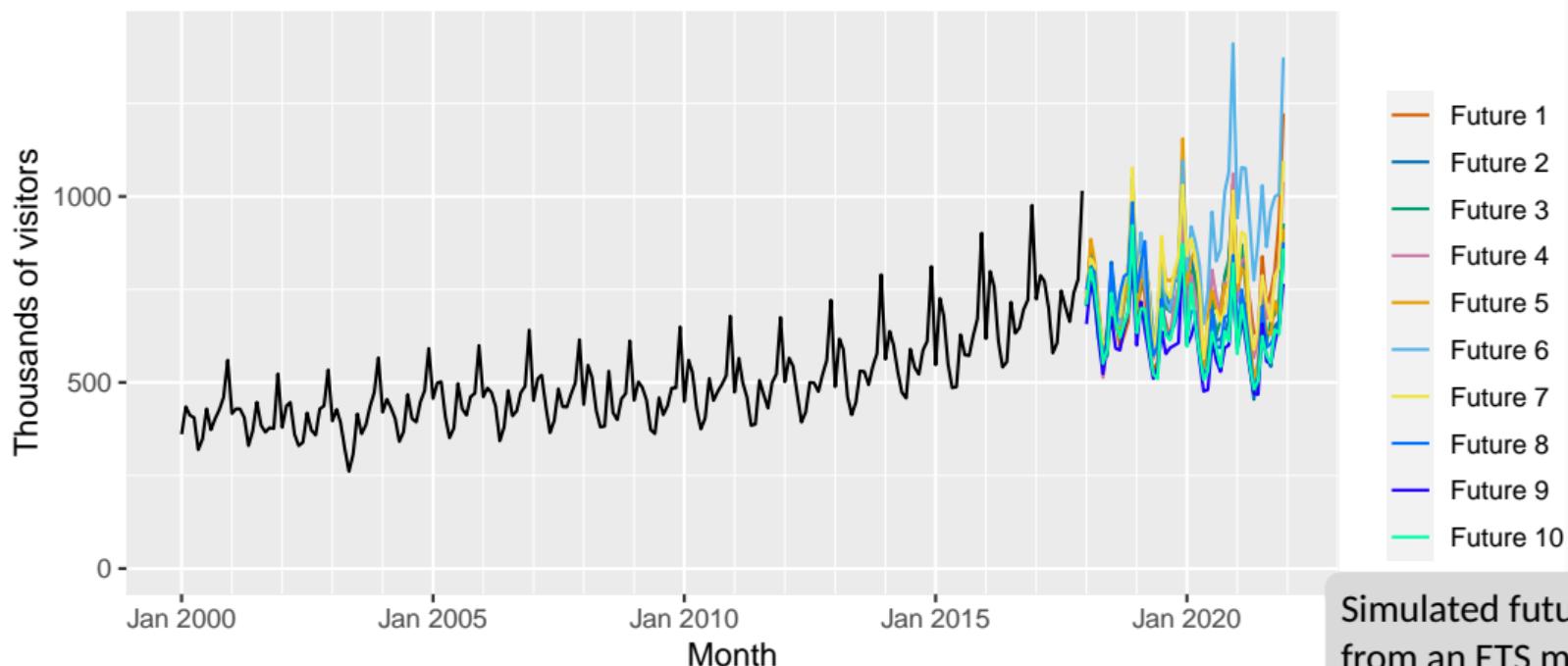


Simulated futures
from an ETS model

Random futures

A forecast is an estimate of the probability distribution of a variable to be observed in the future.

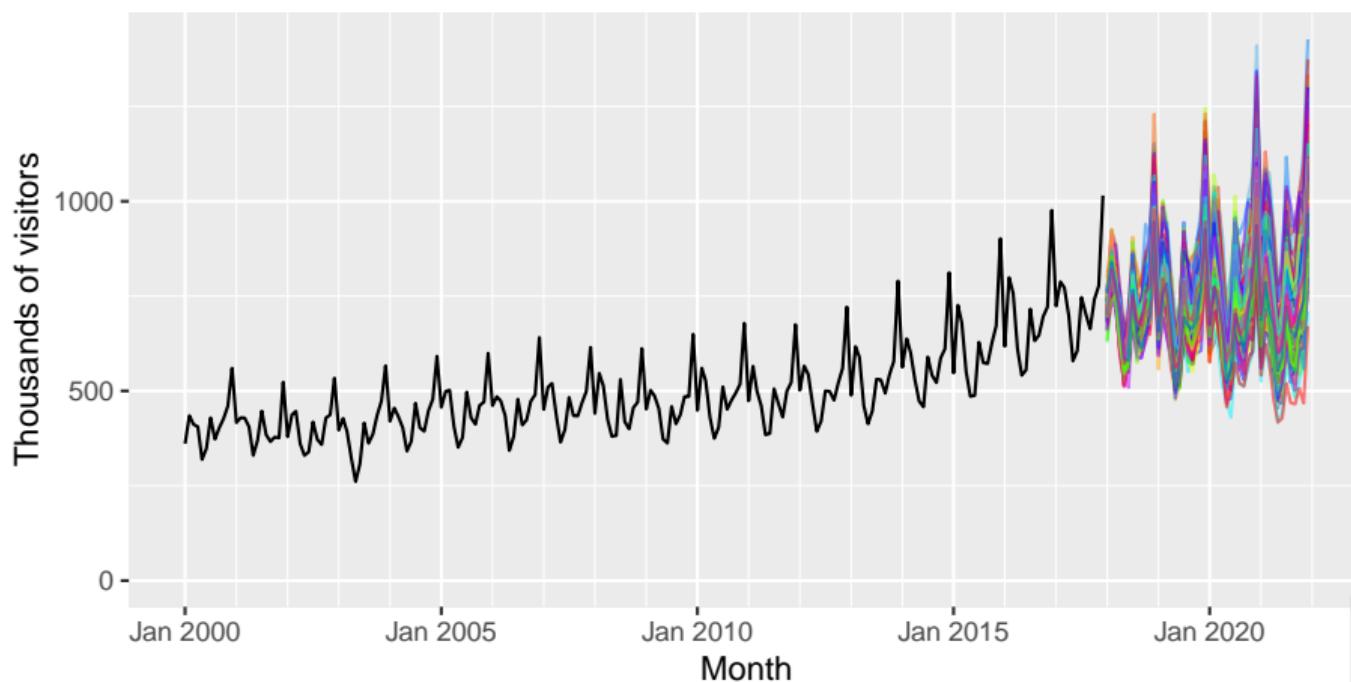
Total short-term visitors to Australia



Random futures

A forecast is an estimate of the probability distribution of a variable to be observed in the future.

Total short-term visitors to Australia

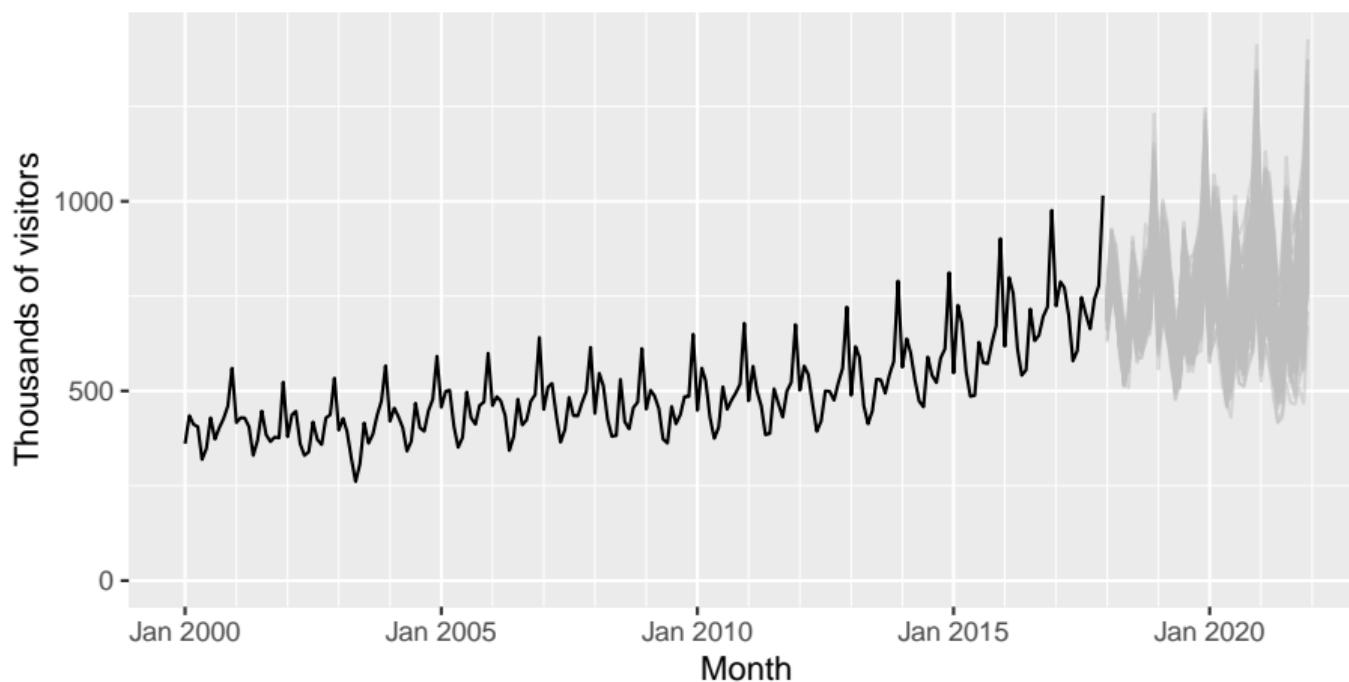


Simulated futures
from an ETS model

Random futures

A forecast is an estimate of the probability distribution of a variable to be observed in the future.

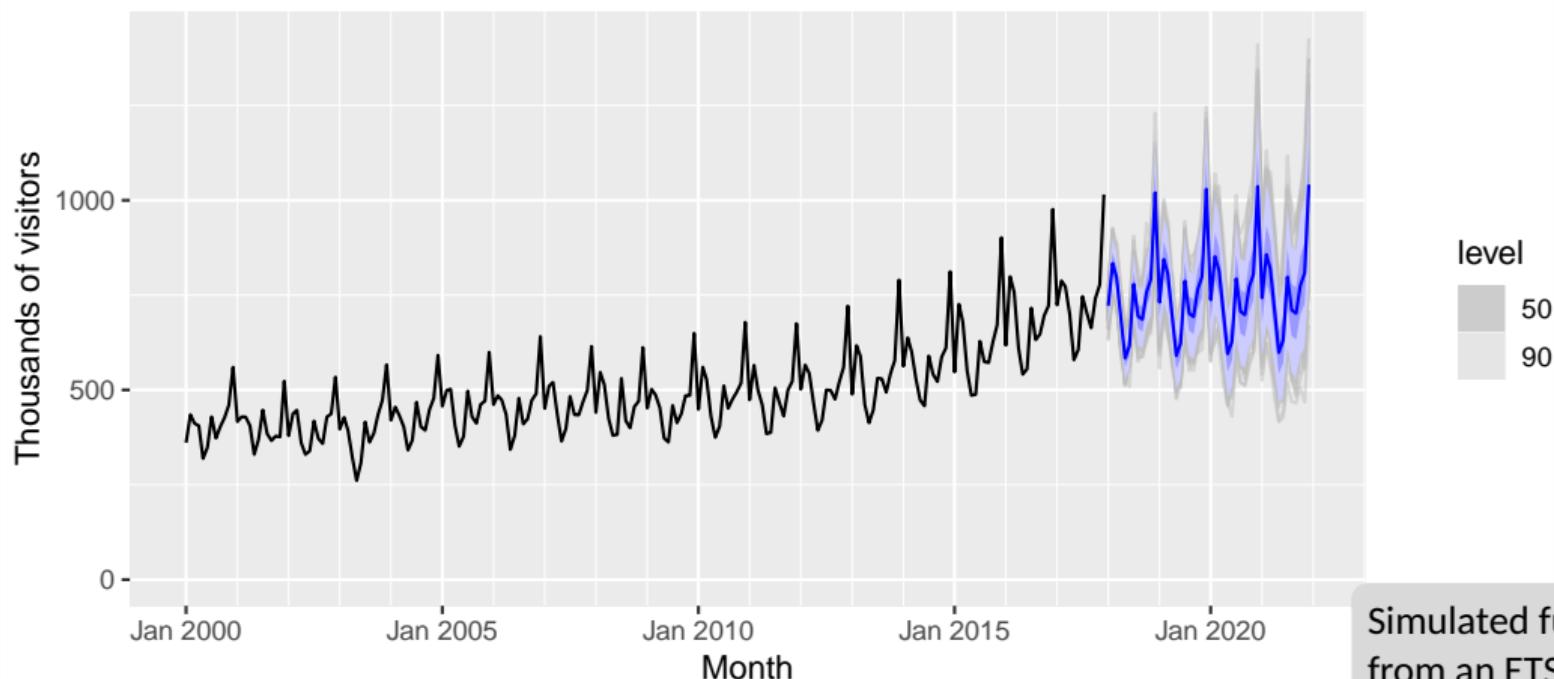
Total short-term visitors to Australia



Random futures

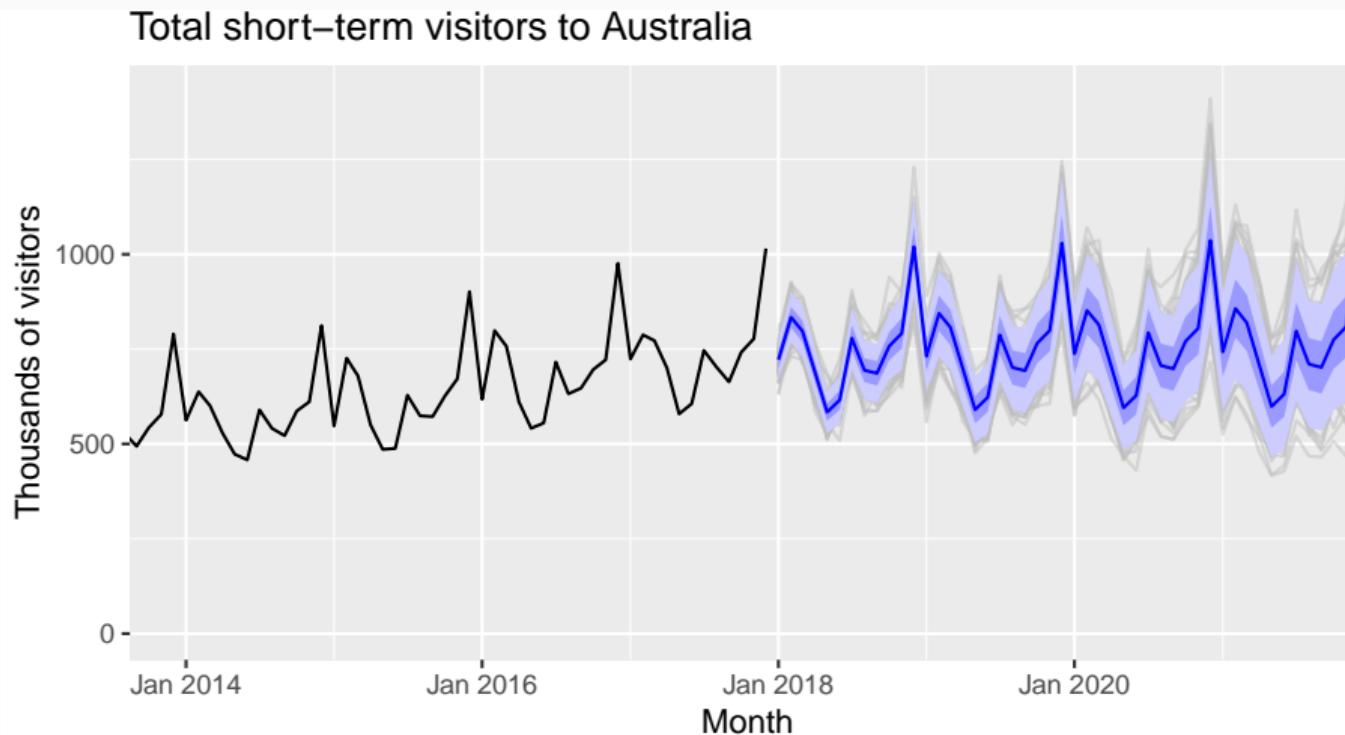
A forecast is an estimate of the probability distribution of a variable to be observed in the future.

Total short-term visitors to Australia



Random futures

A forecast is an estimate of the probability distribution of a variable to be observed in the future.

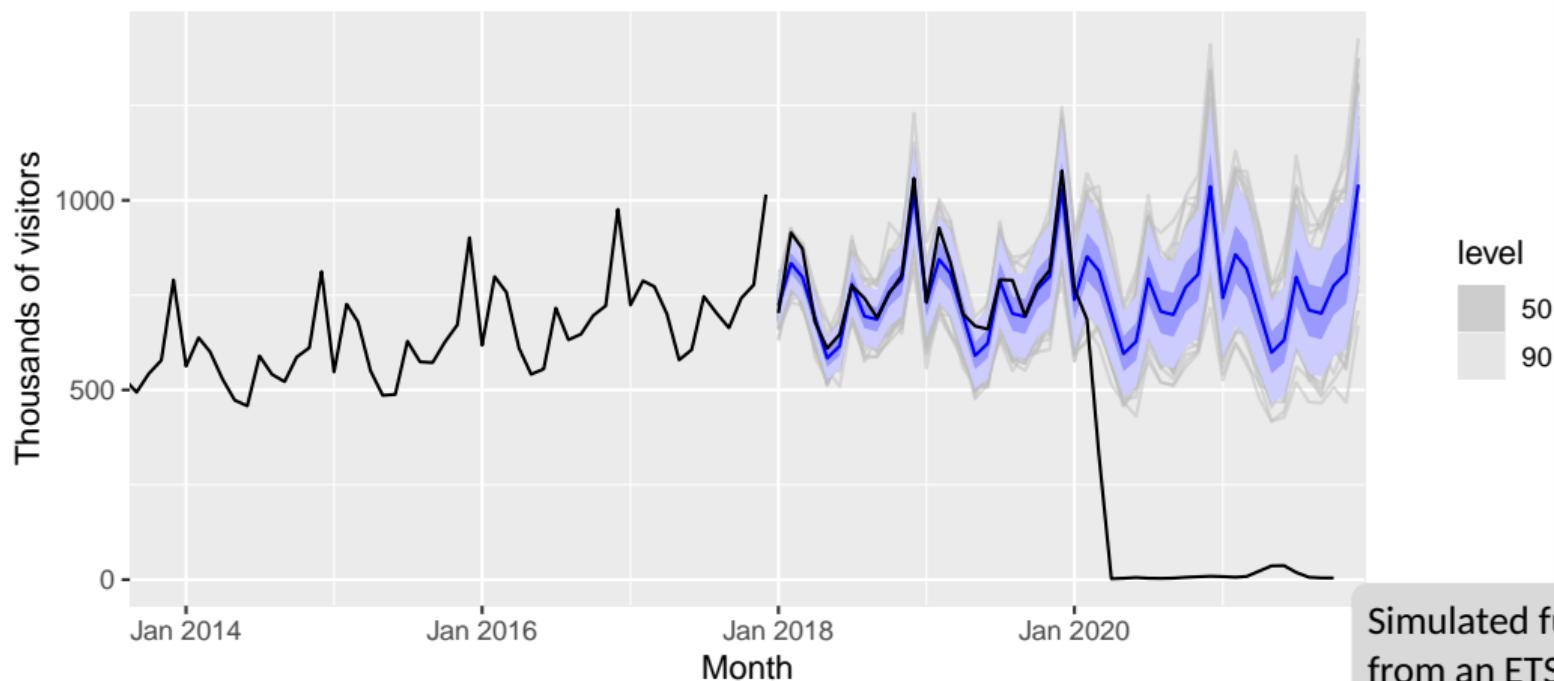


Simulated futures
from an ETS model

Random futures

A forecast is an estimate of the probability distribution of a variable to be observed in the future.

Total short-term visitors to Australia

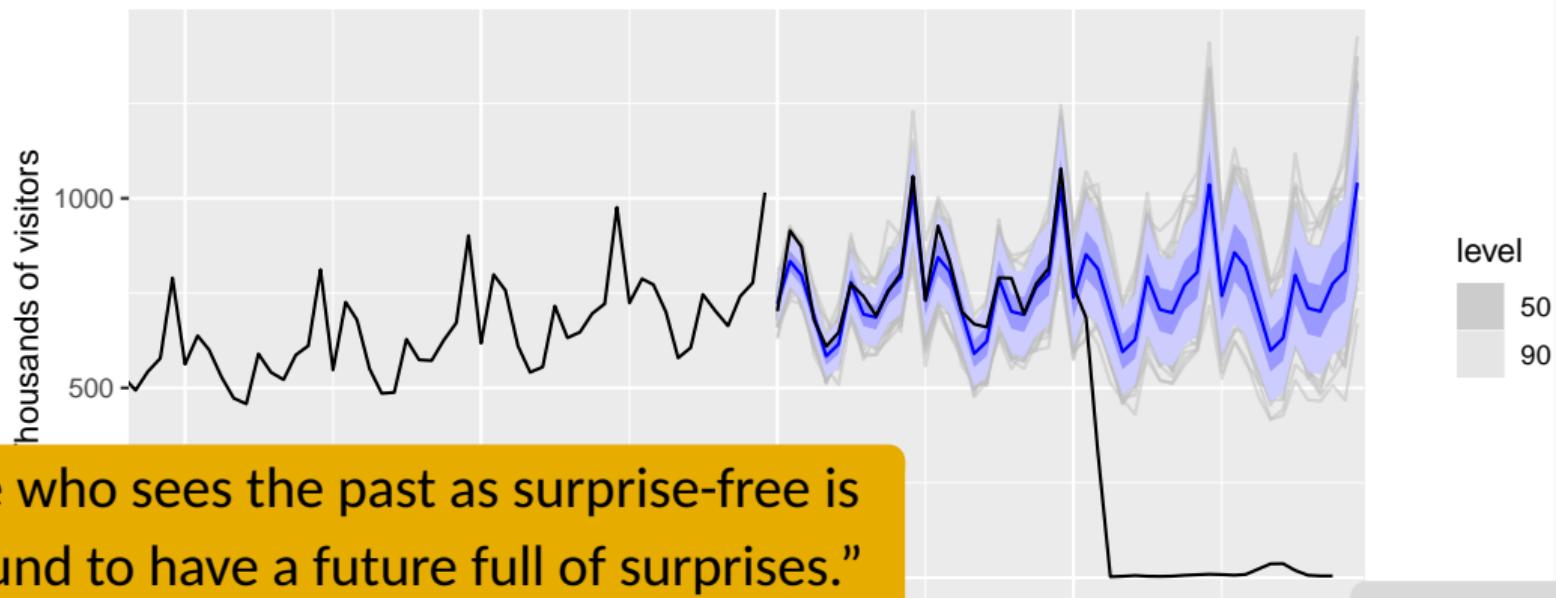


Simulated futures
from an ETS model

Random futures

A forecast is an estimate of the probability distribution of a variable to be observed in the future.

Total short-term visitors to Australia



"He who sees the past as surprise-free is bound to have a future full of surprises."

(Amos Tversky)

Simulated futures
from an ETS model

Outline

- 1 The dark history of forecasting
- 2 What can we forecast?
- 3 Forecasting PBS expenditure
- 4 Forecasting peak electricity demand
- 5 Forecasting COVID-19 cases
- 6 Assessing forecast uncertainty
- 7 The bright future of forecasting

What can we forecast?



What can we forecast?



What can we forecast?



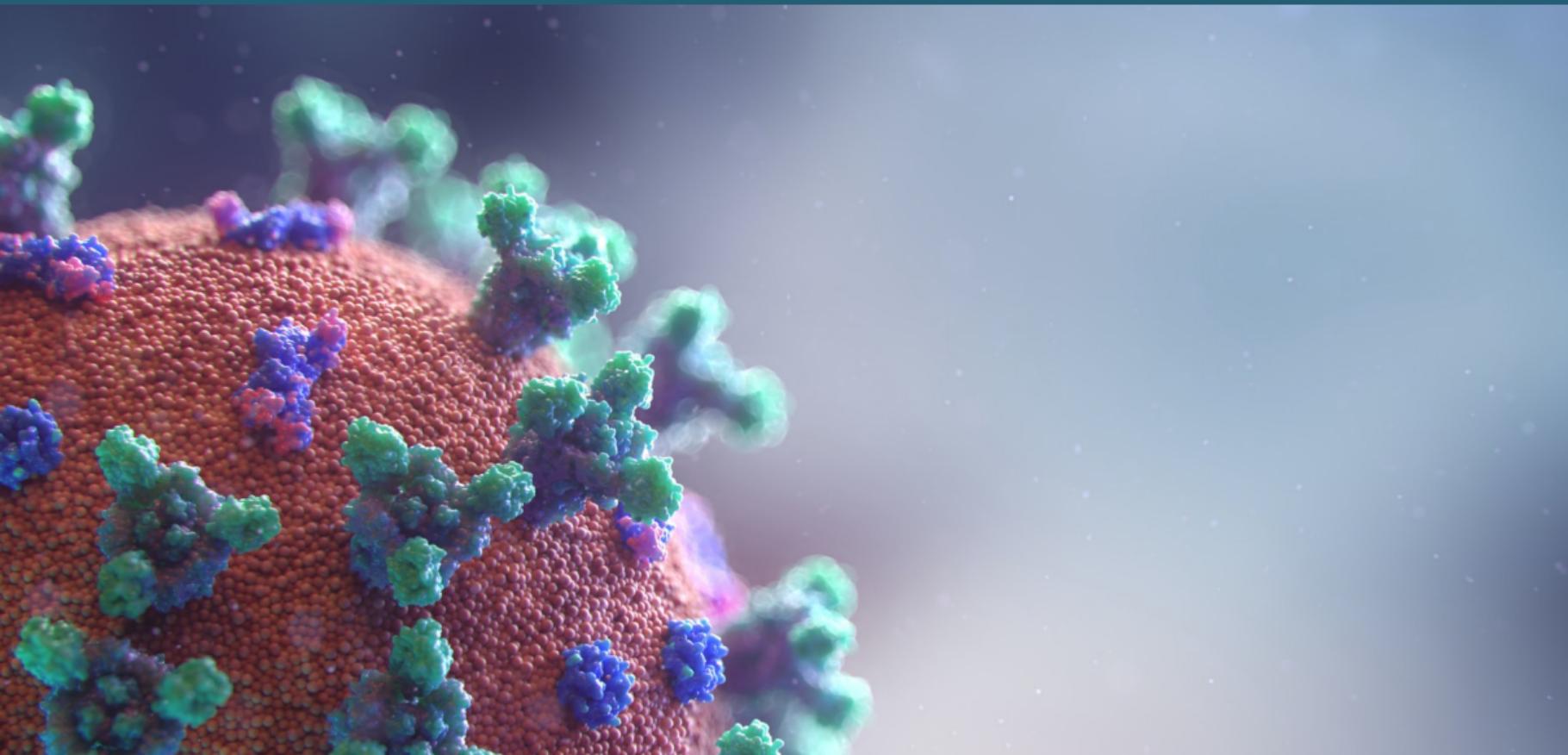
What can we forecast?



What can we forecast?



What can we forecast?



What can we forecast?



Which is easiest to forecast?

- daily electricity demand in 3 days time
- timing of next Halley's comet appearance
- time of sunrise this day next year
- Google stock price tomorrow
- Google stock price in 6 months time
- maximum temperature tomorrow
- exchange rate of \$US/AUS next week
- total sales of drugs in Australian pharmacies next month

Which is easiest to forecast?

- 1 time of sunrise this day next year
- 2 timing of next Halley's comet appearance
- 3 maximum temperature tomorrow
- 4 daily electricity demand in 3 days time
- 5 total sales of drugs in Australian pharmacies next month
- 6 Google stock price tomorrow
- 7 exchange rate of \$US/AUS next week
- 8 Google stock price in 6 months time

Which is easiest to forecast?

- 1 time of sunrise this day next year
 - 2 timing of next Halley's comet appearance
 - 3 maximum temperature tomorrow
 - 4 daily electricity demand in 3 days time
 - 5 total sales of drugs in Australian pharmacies next month
 - 6 Google stock price tomorrow
 - 7 exchange rate of \$US/AUS next week
 - 8 Google stock price in 6 months time
-
- how do we measure “easiest”?
 - what makes something easy/difficult to forecast?

Forecastability factors

Something is easier to forecast if:

- 1 we have a good understanding of the factors that contribute to it, and can measure them.
- 2 there is lots of data available;
- 3 the future is somewhat similar to the past
- 4 the forecasts cannot affect the thing we are trying to forecast.

Outline

- 1 The dark history of forecasting
- 2 What can we forecast?
- 3 Forecasting PBS expenditure
- 4 Forecasting peak electricity demand
- 5 Forecasting COVID-19 cases
- 6 Assessing forecast uncertainty
- 7 The bright future of forecasting

Forecasting PBS expenditure



Forecasting PBS expenditure

The Pharmaceutical Benefits Scheme (PBS) is the Australian government drugs subsidy scheme.

- Many drugs bought from pharmacies are subsidised to allow more equitable access to modern drugs.
- The cost to government is determined by the number and types of drugs purchased. Currently nearly 1% of GDP.
- The total cost is budgeted based on forecasts of drug usage.

Forecasting PBS expenditure



ABC News Online
AUSTRALIAN BROADCASTING CORPORATION

Select a Topic from the list below

- ▶ [Top Stories](#)
- ▶ [Just In](#)
- ▶ [World](#)
- ▶ [Asia-Pacific](#)
- ▶ [Business](#)
- ▶ [Sport](#)
- ▶ [Arts](#)
- ▶ [Sci Tech](#)
- ▶ [Indigenous](#)
- ▶ [Weather](#)
- ▶ [Rural](#)
- ▶ [Local News](#)
- ▶ [Broadband](#)

Click "Refresh" or "Reload" on your browser for the latest edition.

POLITICS

Opp demands drug price restriction after PBS budget blow-out

The Federal Opposition has called for tighter controls on drug prices after the Pharmaceutical Benefits Scheme (PBS) budget blew out by almost \$800 million.

The money was spent on two new drugs including the controversial anti-smoking aid Zyban, which dropped in price from \$220 to \$22 after it was listed on the



NewsRadio
Streaming audio news
LISTEN: [WMP](#) | [Real](#)

This Bulletin: Wed, May 30 2001 6:22 PM AEST

the Public Record
For full election coverage

FEATURES

Public Record
Federal Election 2001

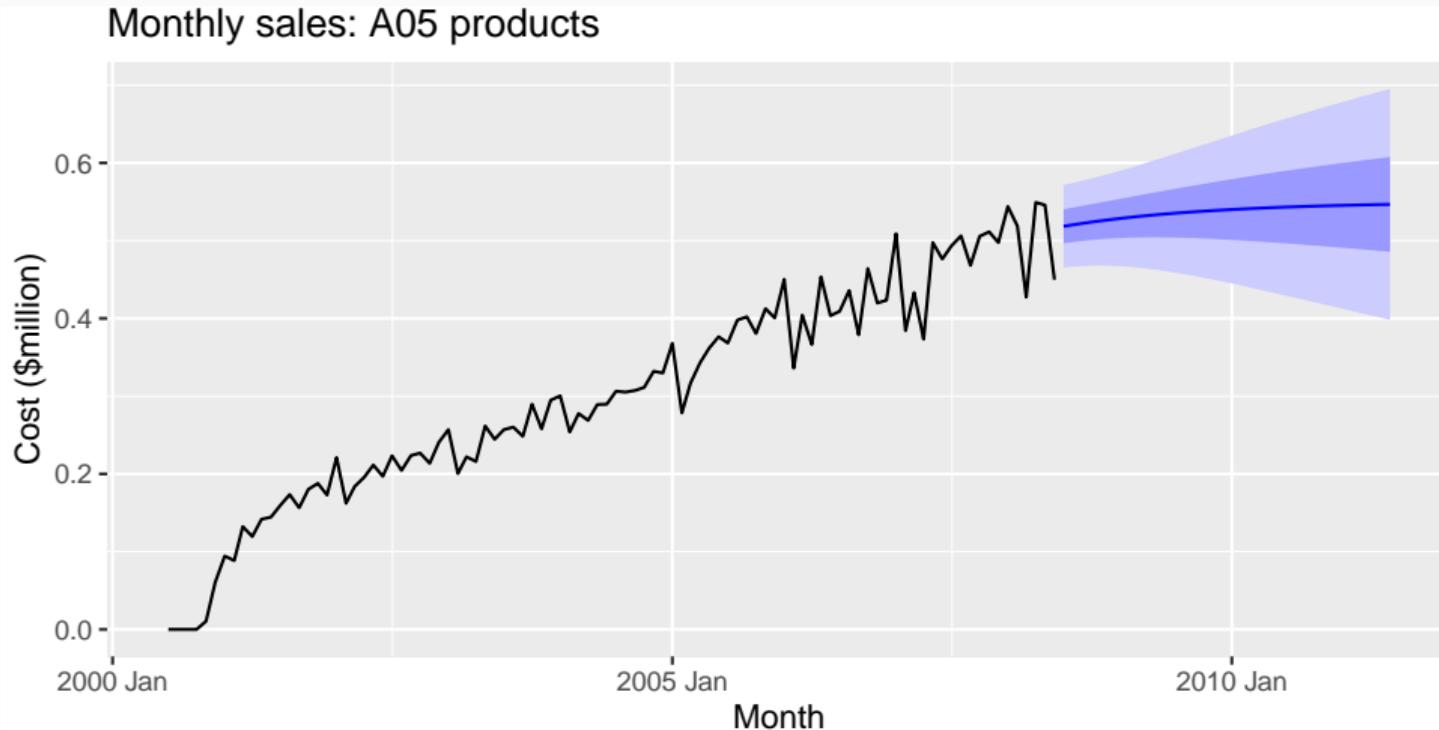
For a fresh perspective on the federal election, reach into ABC Online's campaign weblog, [The Poll Vault](#).

Forecasting PBS expenditure

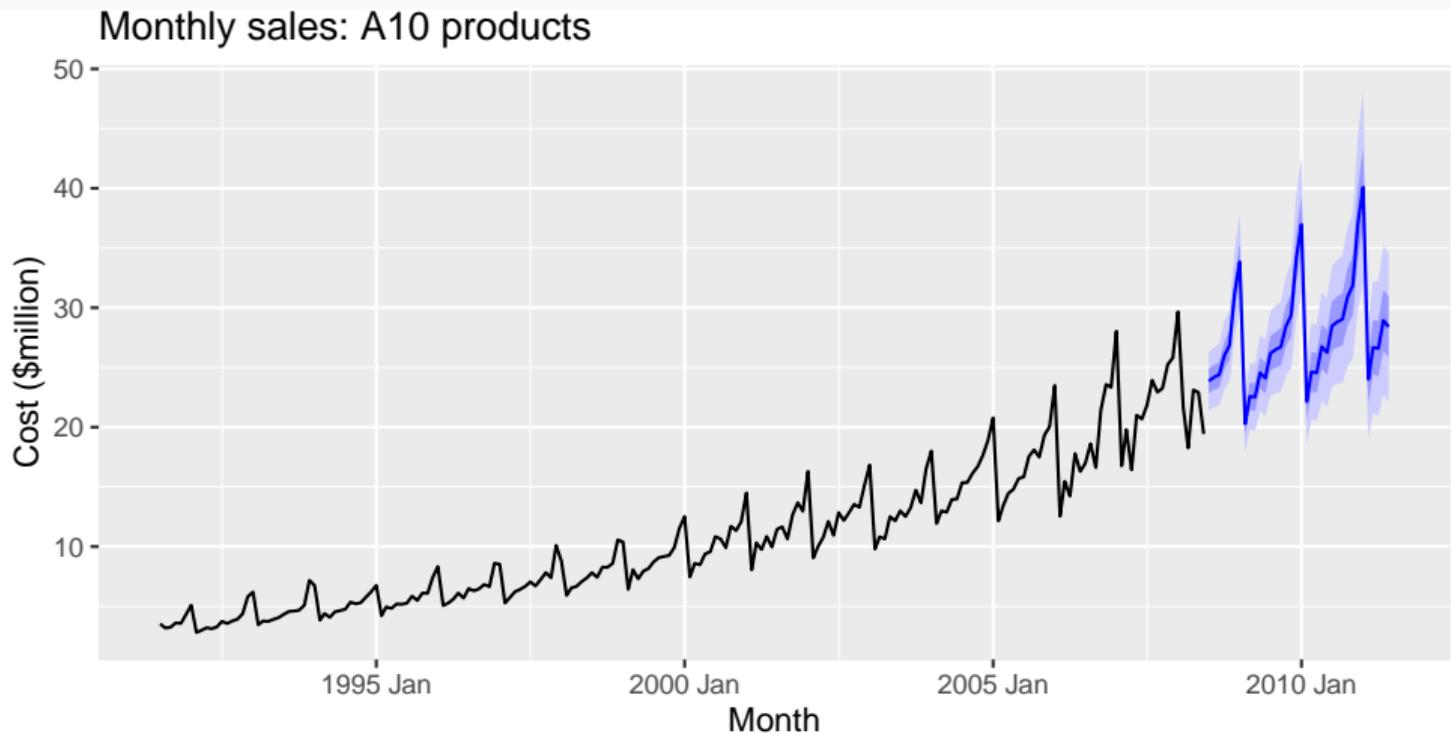
The phone call (2001)

- \$4.5 billion PBS budget, under-forecasted by \$800 million.
- Thousands of products. Seasonal demand.
- Subject to covert marketing, volatile products, uncontrollable expenditure.
- Although monthly data available for 10 years, data are aggregated to annual values, and only the first three years are used in estimating the forecasts.
- All forecasts being done with the FORECAST function in MS-Excel!

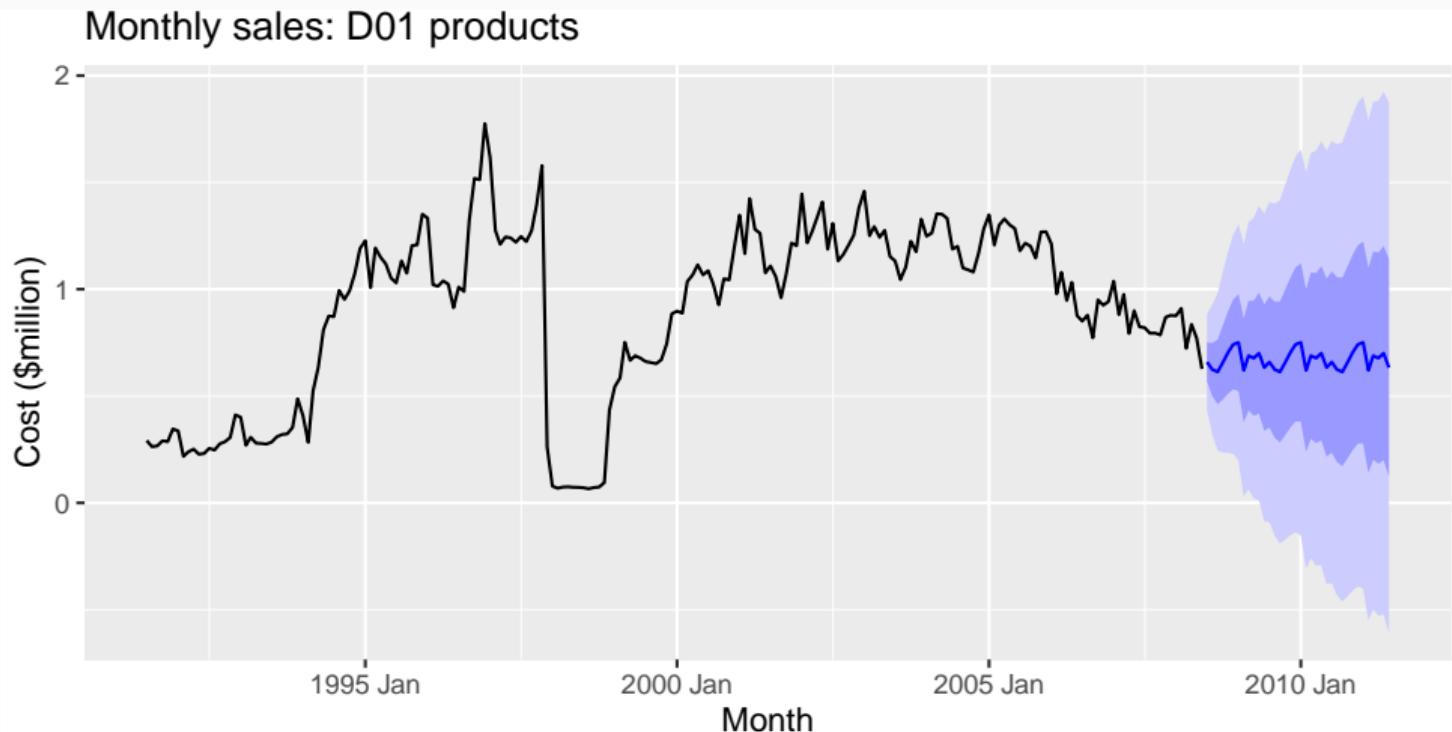
ETS forecasts of PBS data



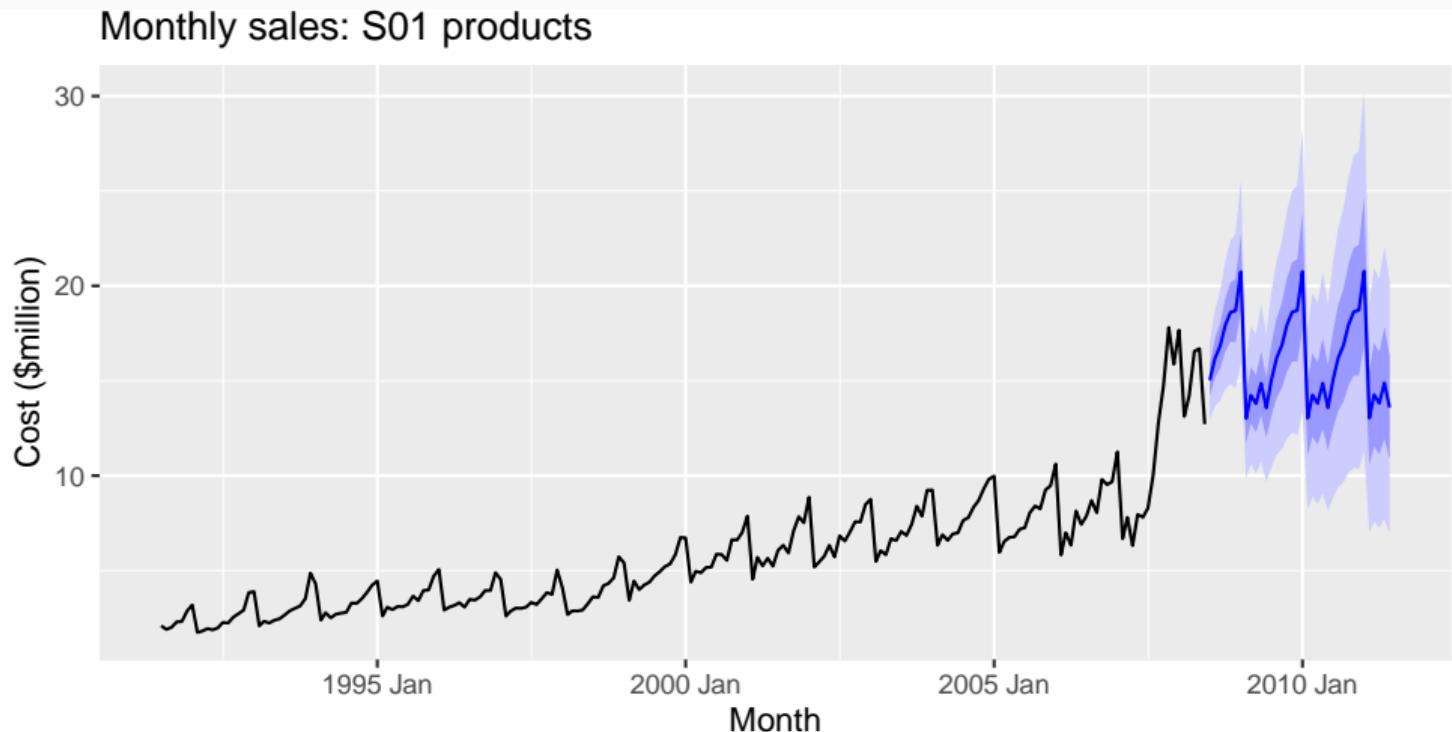
ETS forecasts of PBS data



ETS forecasts of PBS data



ETS forecasts of PBS data



Forecasting PBS expenditure

- Developed an automatic forecasting algorithm for exponential smoothing state space models.
- Exponential smoothing models allowed for time-changing trend and seasonal patterns.
- Forecast average percentage error reduced from 15–20% to 0.6%.
- Theory and algorithm published as Hyndman et al (IJF, 2002).
- Now implemented in R as `ets()` in `forecast` package, as `ETS()` function in `fable` package, and in Tableau and elsewhere.
- NOT implemented in FORECAST.ETS function in MS-Excel.

Forecastability factors

- 1 we have a good understanding of the factors that contribute to it, and can measure them.
- 2 there is lots of data available;
- 3 the future is somewhat similar to the past
- 4 the forecasts cannot affect the thing we are trying to forecast.

Outline

- 1 The dark history of forecasting
- 2 What can we forecast?
- 3 Forecasting PBS expenditure
- 4 Forecasting peak electricity demand
- 5 Forecasting COVID-19 cases
- 6 Assessing forecast uncertainty
- 7 The bright future of forecasting

Forecasting peak electricity demand



Forecasting peak electricity demand

The phone call (2006)

- We want to forecast the peak electricity demand in a half-hour period in twenty years time.
- We have fifteen years of half-hourly electricity data, temperature data and some economic and demographic data.
- The location is South Australia: home to the most volatile electricity demand in the world.

Forecasting peak electricity demand

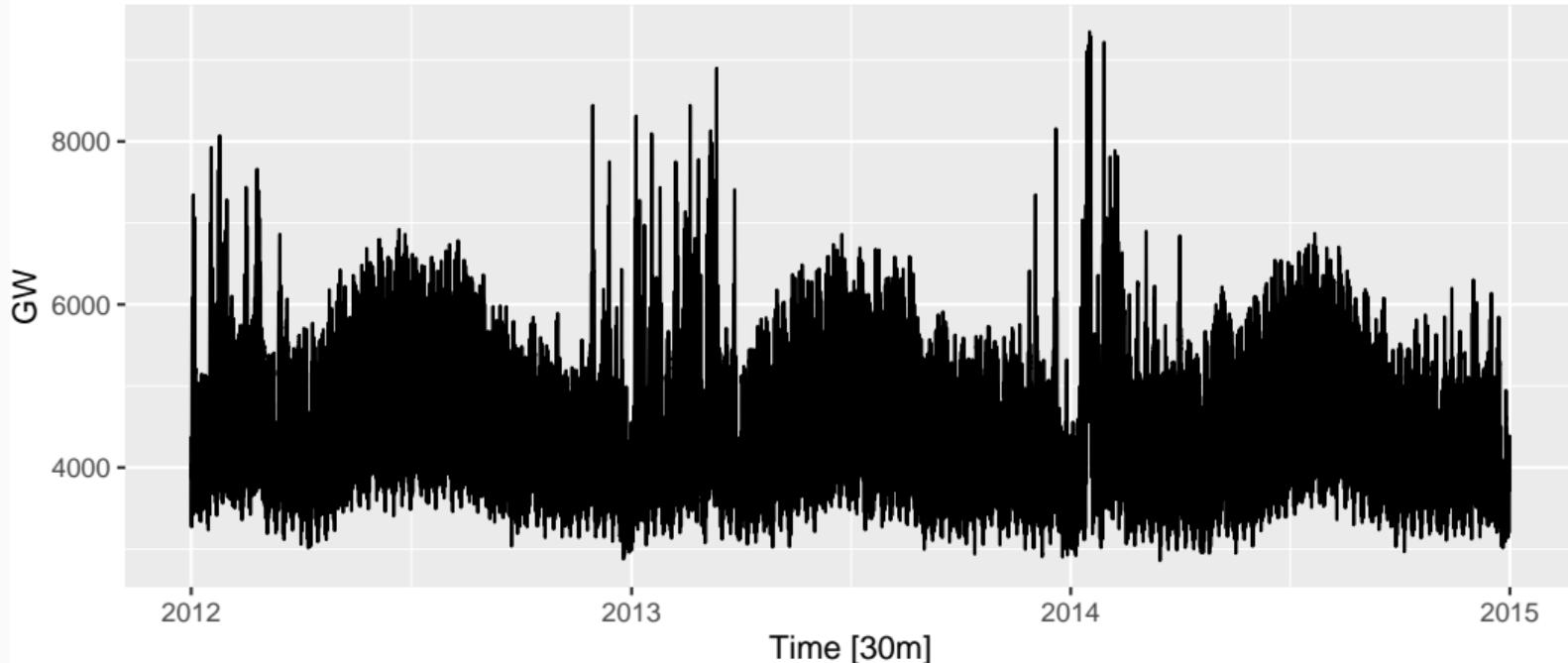
The phone call (2006)

- We want to forecast the peak electricity demand in a half-hour period in twenty years time.
- We have fifteen years of half-hourly electricity data, temperature data and some economic and demographic data.
- The location is South Australia: home to the most volatile electricity demand in the world.

Sounds impossible?

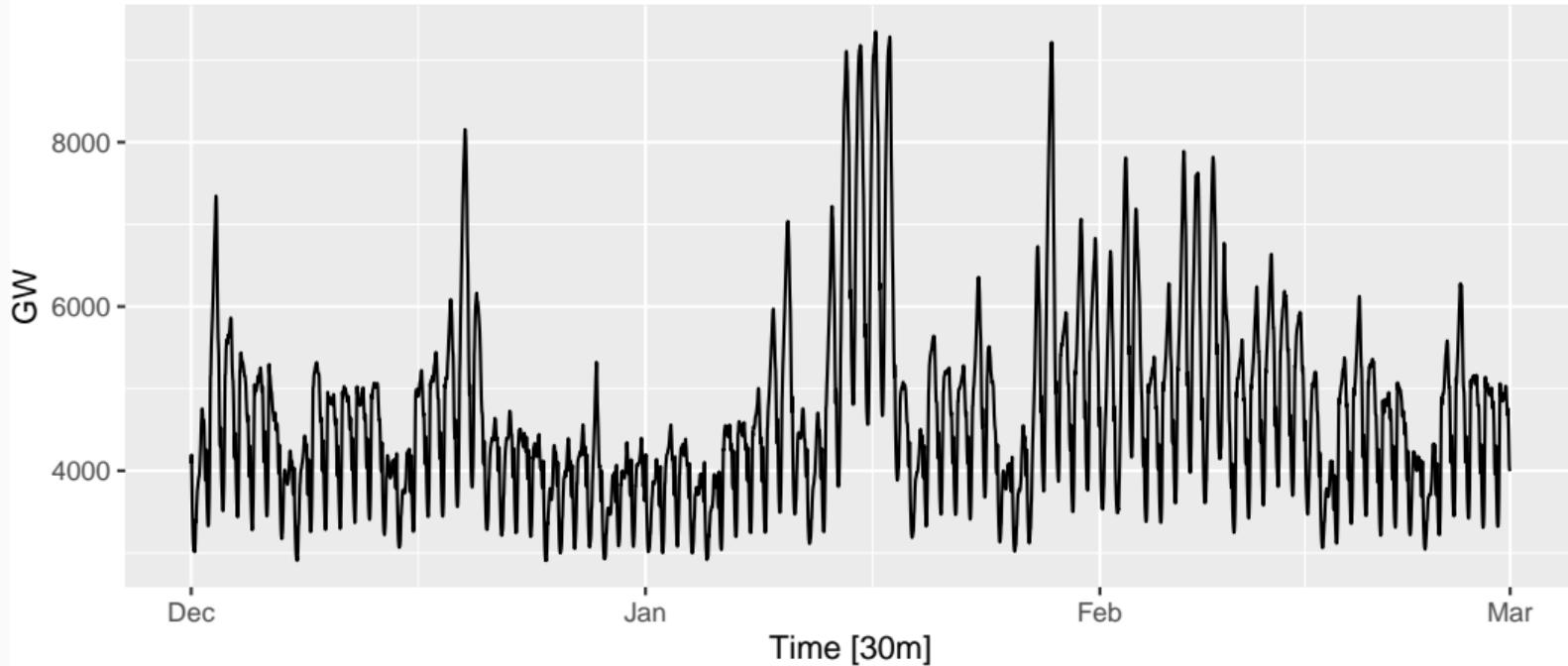
Forecasting peak electricity demand

VIC statewide demand

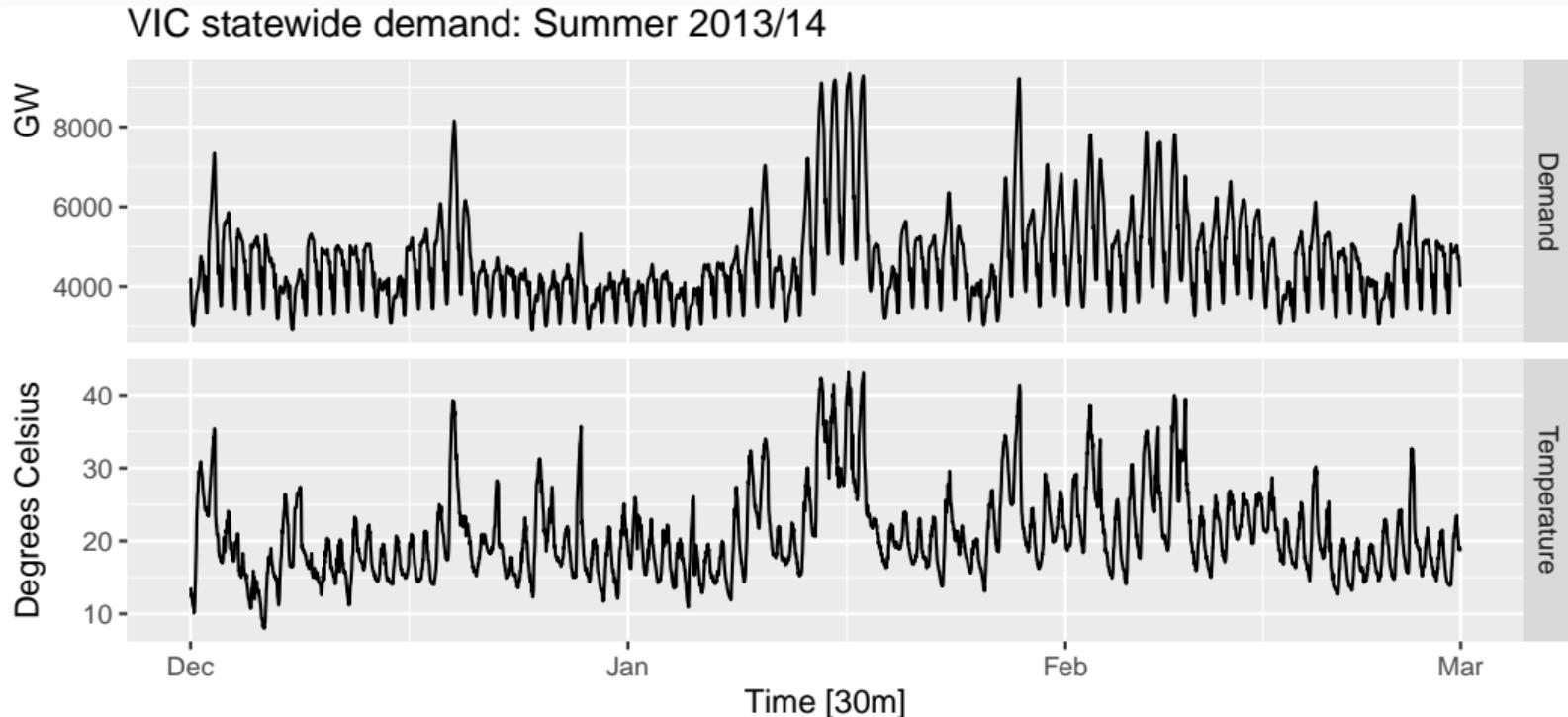


Forecasting peak electricity demand

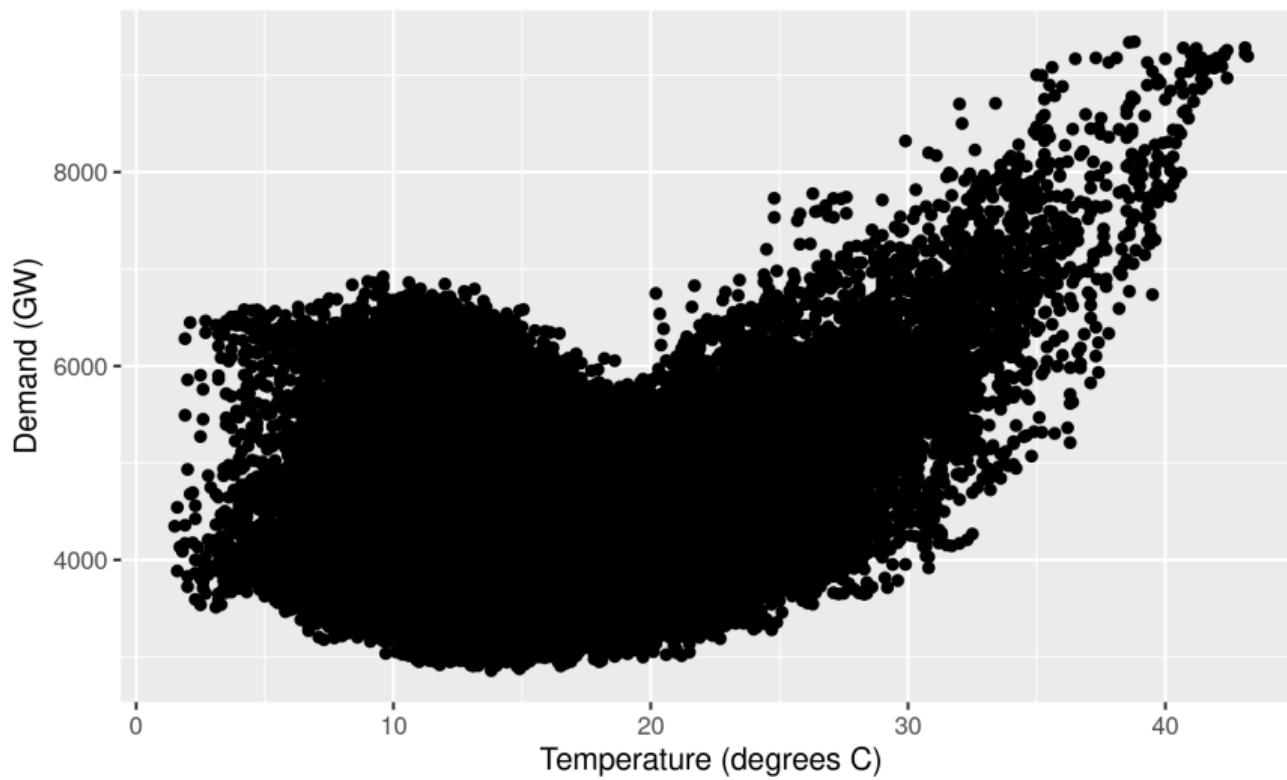
VIC statewide demand: Summer 2013/14



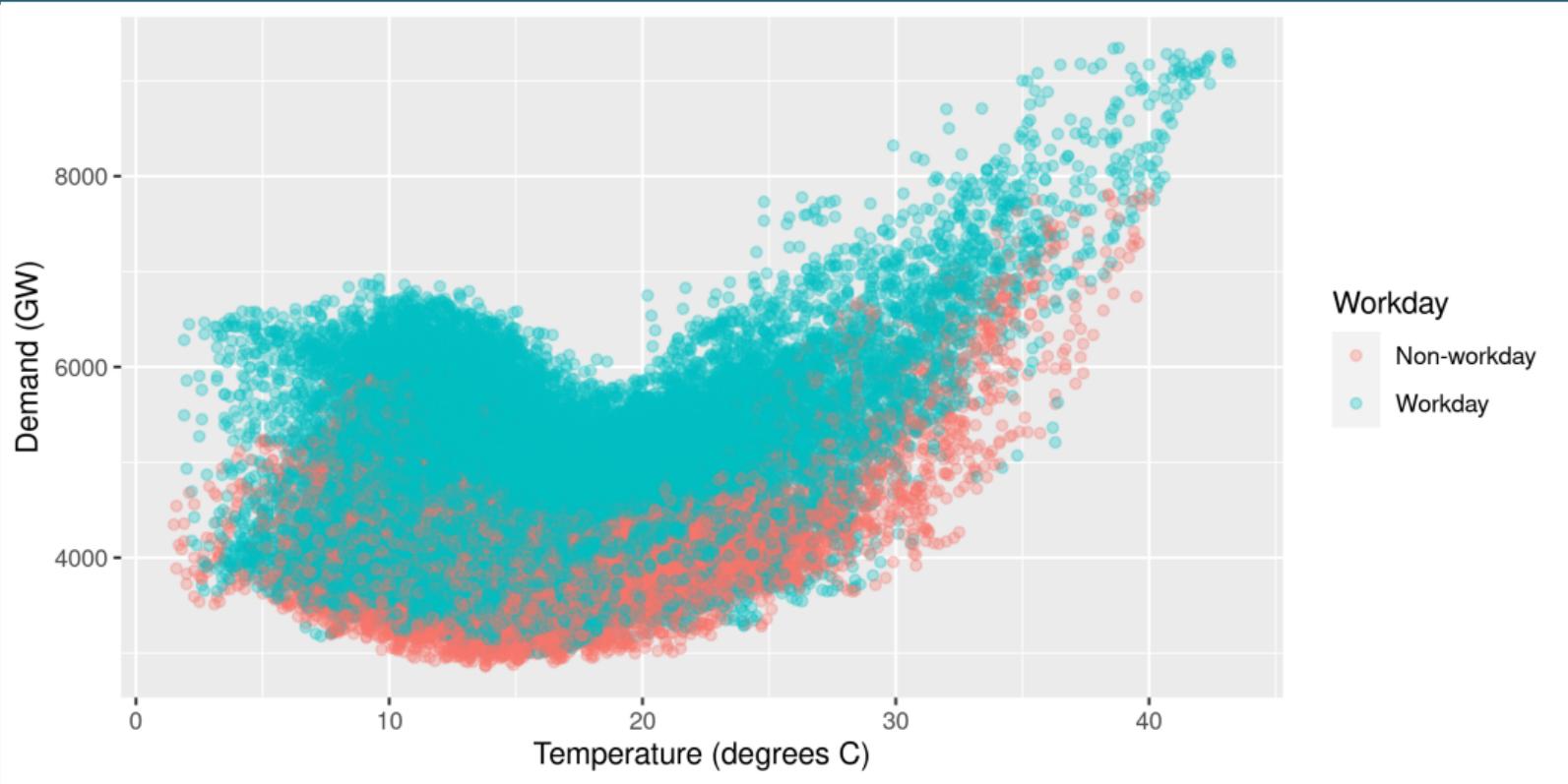
Forecasting peak electricity demand



Forecasting peak electricity demand



Forecasting peak electricity demand



Forecasting peak electricity demand

Forecasting peak electricity demand

Predictors

- calendar effects: time of day, day of week, time of year, holidays, etc.
- prevailing and recent weather conditions
- climate change
- demand response incentives
- changing technology
- economic and demographic changes

We build a nonparametric stochastic model of demand as a function of these predictors.

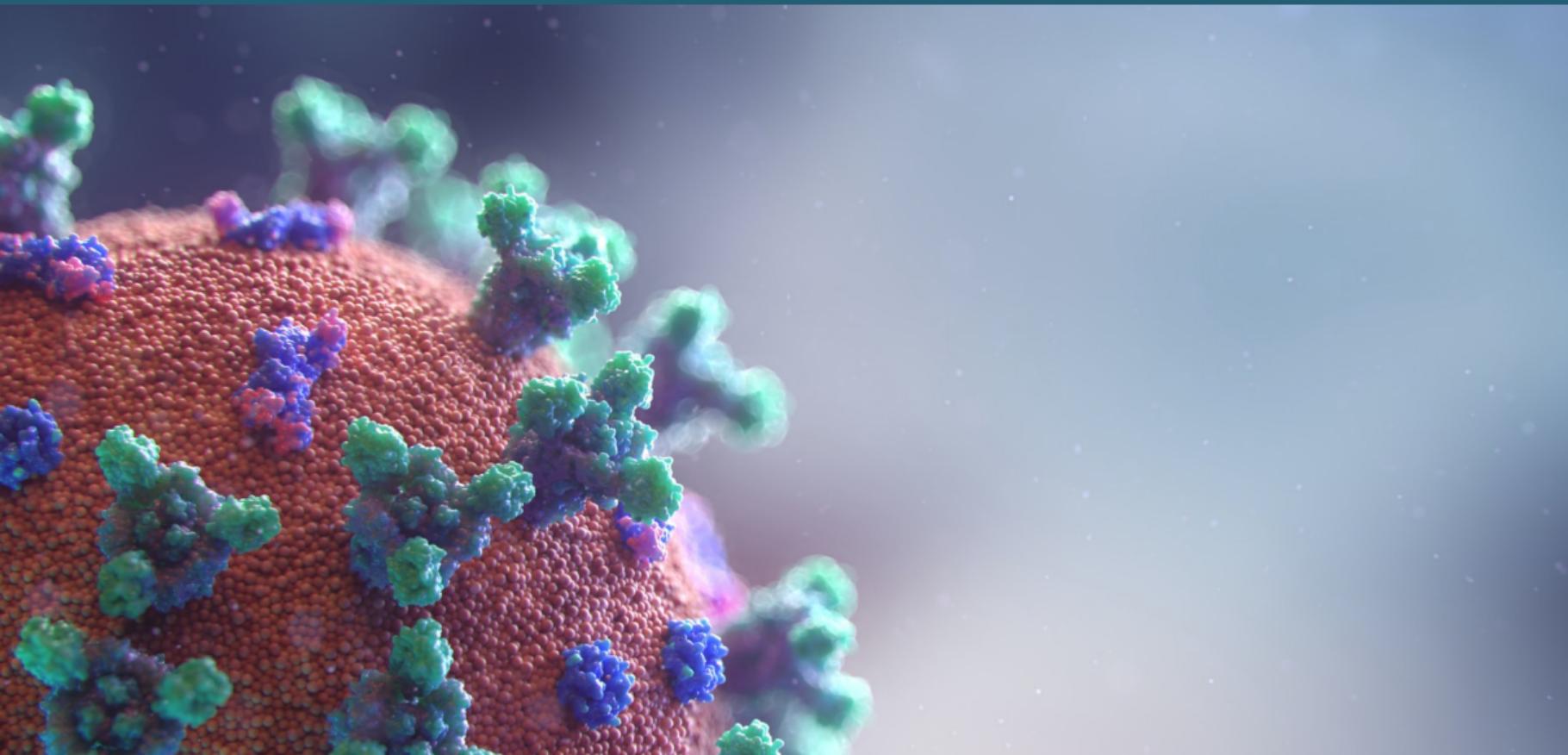
Forecastability factors

- 1 we have a good understanding of the factors that contribute to it, and can measure them.
- 2 there is lots of data available;
- 3 the future is somewhat similar to the past
- 4 the forecasts cannot affect the thing we are trying to forecast.

Outline

- 1 The dark history of forecasting
- 2 What can we forecast?
- 3 Forecasting PBS expenditure
- 4 Forecasting peak electricity demand
- 5 Forecasting COVID-19 cases
- 6 Assessing forecast uncertainty
- 7 The bright future of forecasting

Forecasting COVID-19 cases



Australian Health Protection Principal Committee

The Australian Health Protection Principal Committee is the key decision-making committee for national health emergencies. It comprises all state and territory Chief Health Officers and is chaired by the Australian Chief Medical Officer.

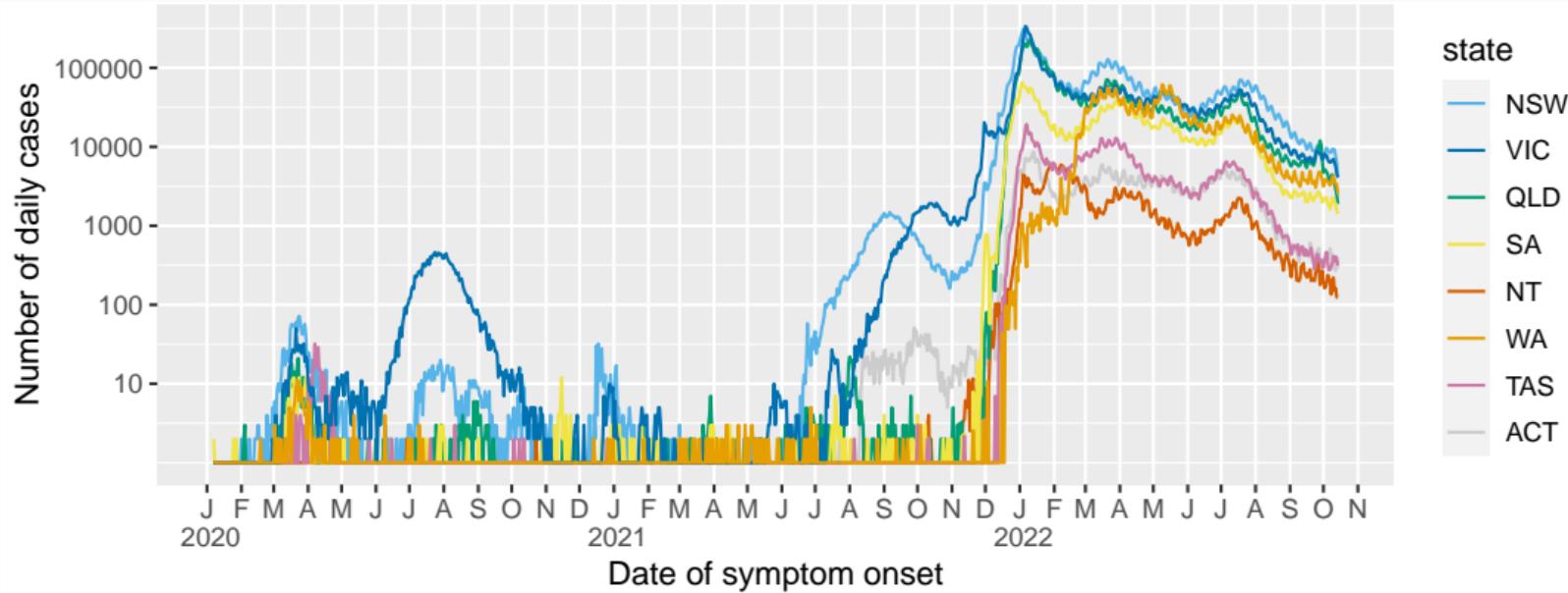
COVID-19 forecasting group

- | | | |
|---------------------|------------------------|-----------------|
| ■ Adeshina Adekunle | ■ James M McCaw | ■ Nick Golding |
| ■ August Hao | ■ Joshua V Ross | ■ Peter Dawson |
| ■ David J Price | ■ Michael Lydeamore | ■ Rob J Hyndman |
| ■ Dennis Liu | ■ Mitchell O'Hara-Wild | ■ Robert Moss |
| ■ Freya M Shearer | ■ Nicholas Tierney | ■ Ruarai Tobin |
| ■ Gerry Ryan | ■ Pablo Montero-Manso | ■ Tobin South |

Data sources

- Case-level data of all positive COVID-19 tests: onset and detection times.
- Daily population mobility data from Google, Apple & Facebook
- Weekly non-household contact surveys
- Weekly behavioural surveys
- Daily case numbers from many countries and regions via the Johns Hopkins COVID-19 repository

Case numbers



- Recent case numbers are uncertain and incomplete as date of onset is not known until symptoms show and a test is obtained.

A model ensemble

Model 1: SEIIR (Uni Melbourne/Doherty Institute)

- Stochastic compartmental model with time-varying effective reproduction number.

Model 2: Generative model (Uni Adelaide)

- Simulation with three types of infectious individuals: imported, asymptomatic, symptomatic

Model 3: Global AR model (Monash)

- Single model fitted to all Johns Hopkins data from countries and regions with sufficient data.
- Series with obvious anomalies removed.

Forecasting ensemble

- Forecasts obtained from a equally-weighted mixture distribution of the component forecasts.
- Also known as “linear pooling”
- Works best when individual models are over-confident and use different data sources.

Ensemble forecasts: Victoria

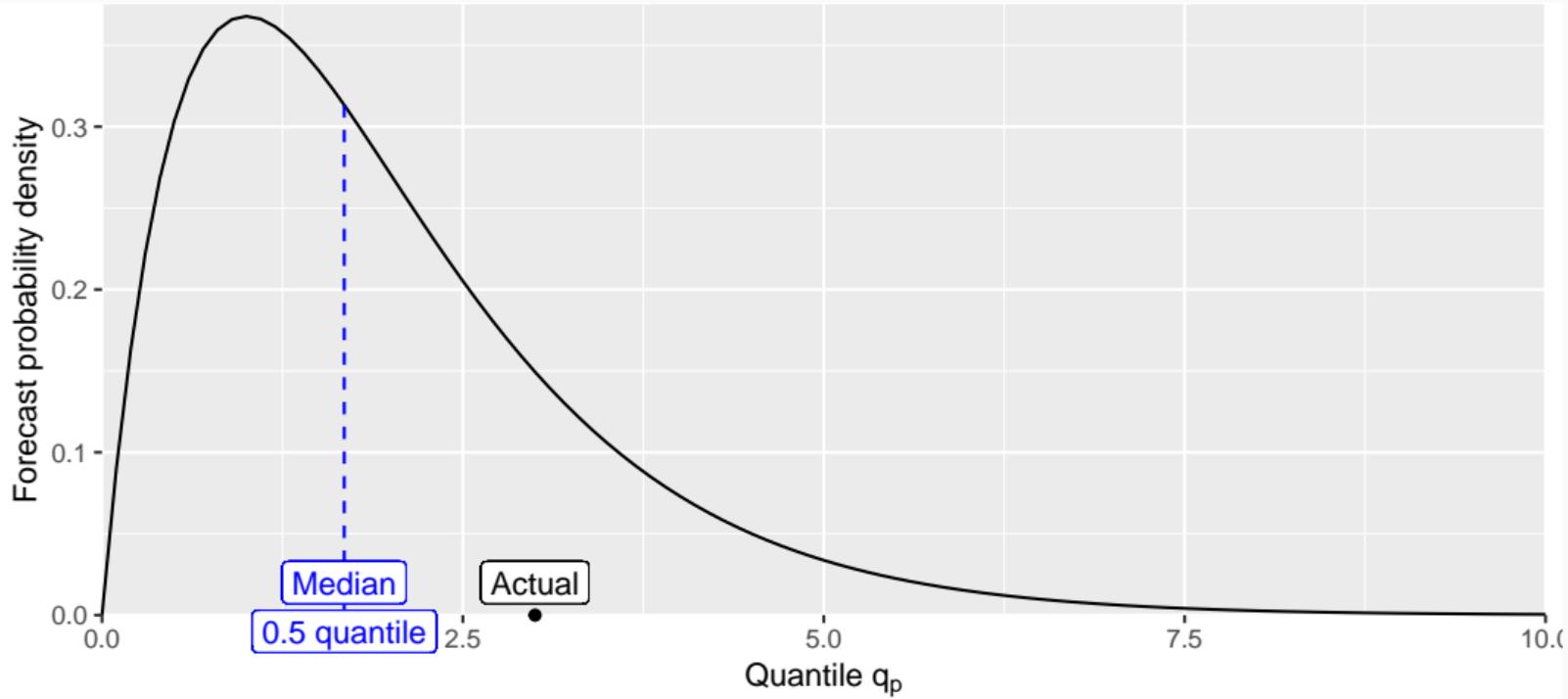
Forecastability factors

- 1 we have a good understanding of the factors that contribute to it, and can measure them.
- 2 there is lots of data available;
- 3 the future is somewhat similar to the past
- 4 the forecasts cannot affect the thing we are trying to forecast.

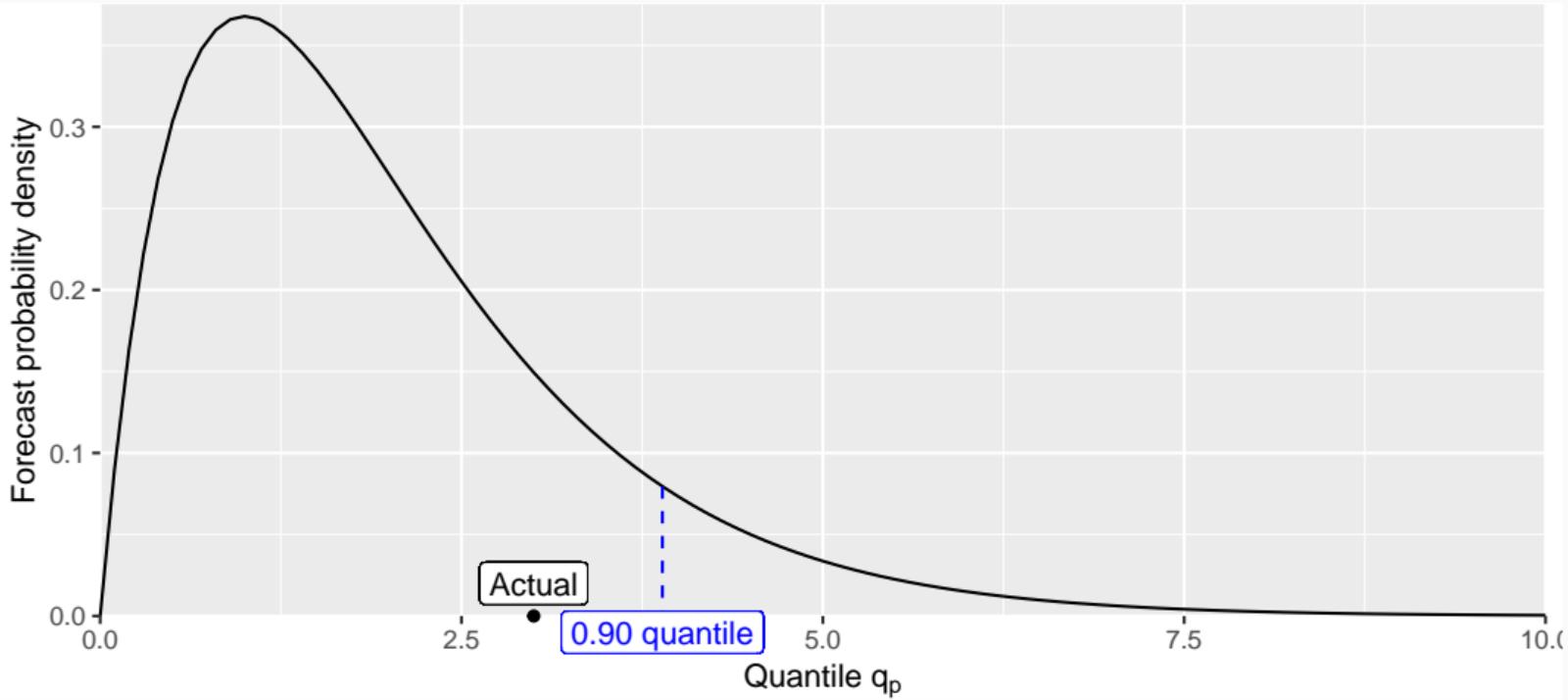
Outline

- 1 The dark history of forecasting
- 2 What can we forecast?
- 3 Forecasting PBS expenditure
- 4 Forecasting peak electricity demand
- 5 Forecasting COVID-19 cases
- 6 Assessing forecast uncertainty
- 7 The bright future of forecasting

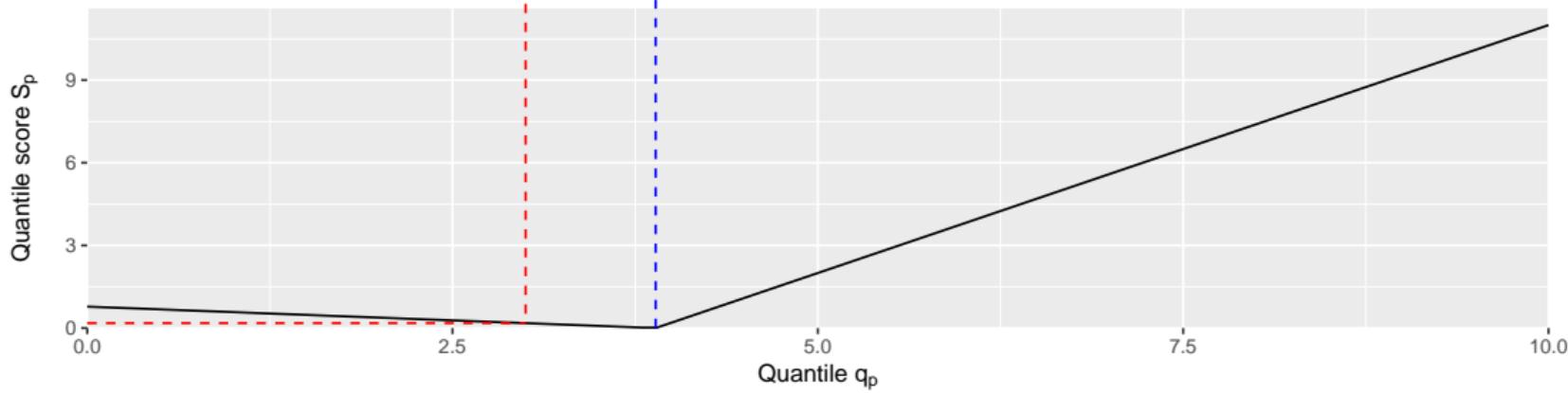
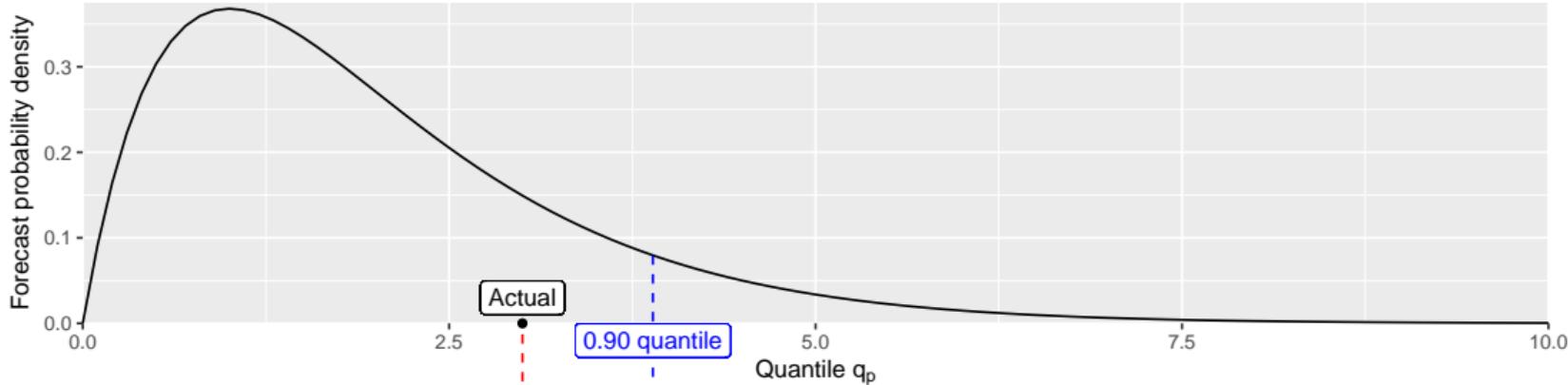
Evaluating probabilistic forecasts



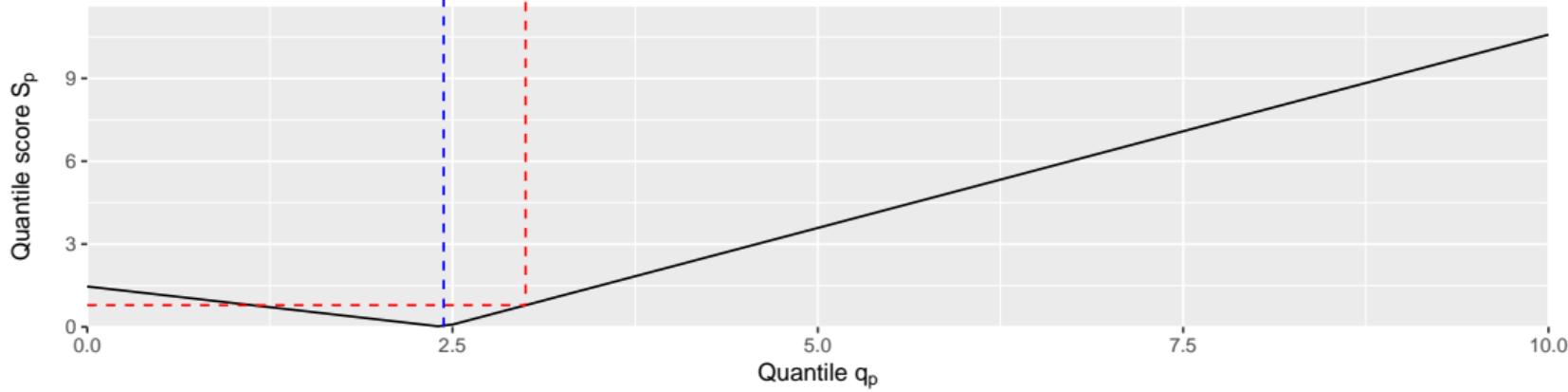
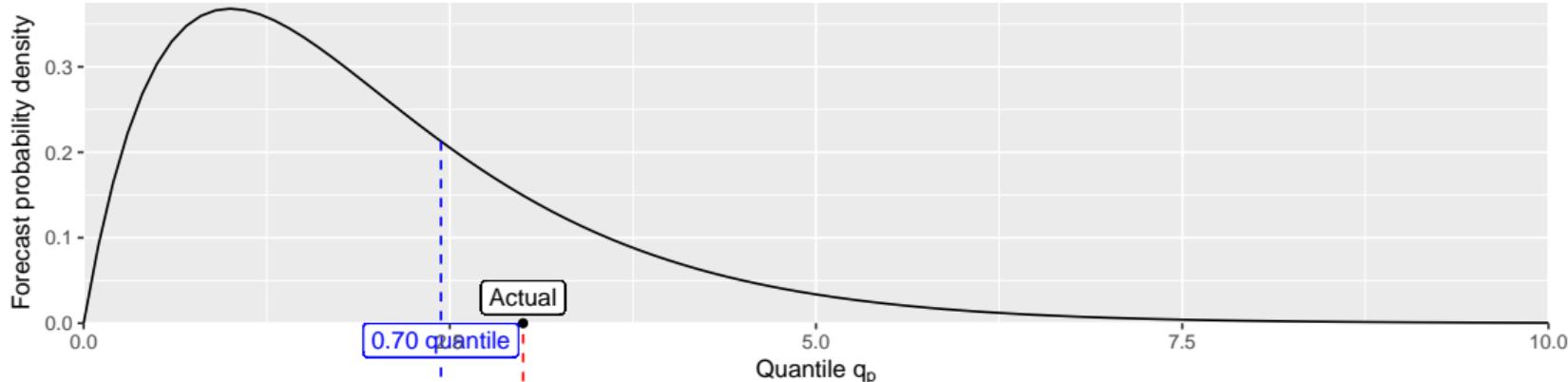
Evaluating probabilistic forecasts



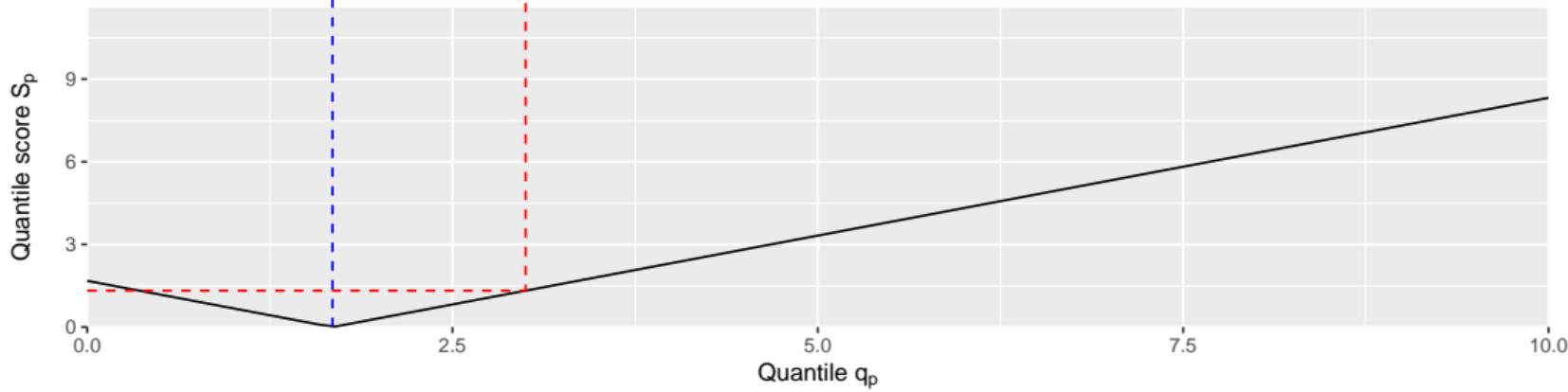
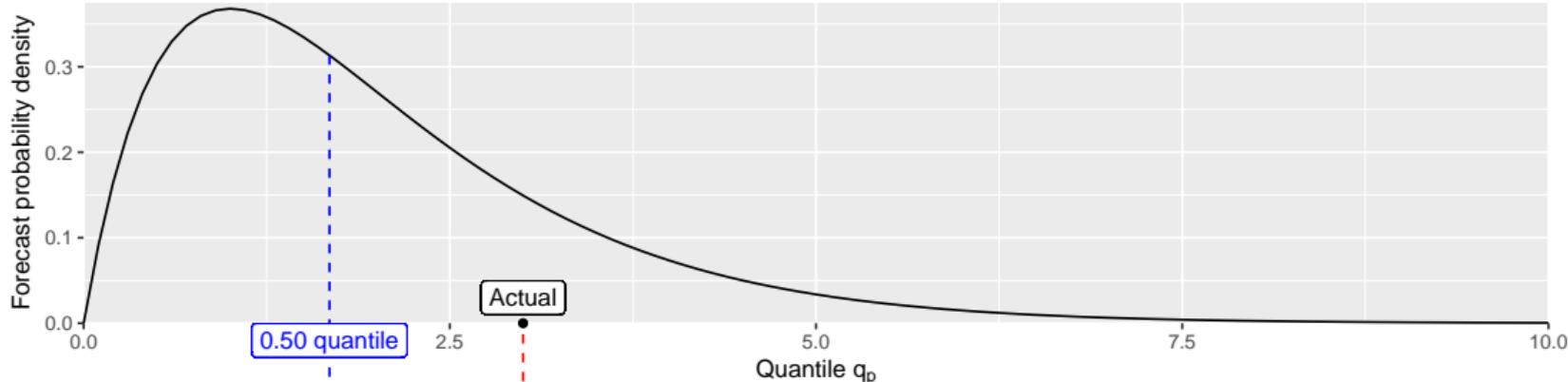
Evaluating probabilistic forecasts



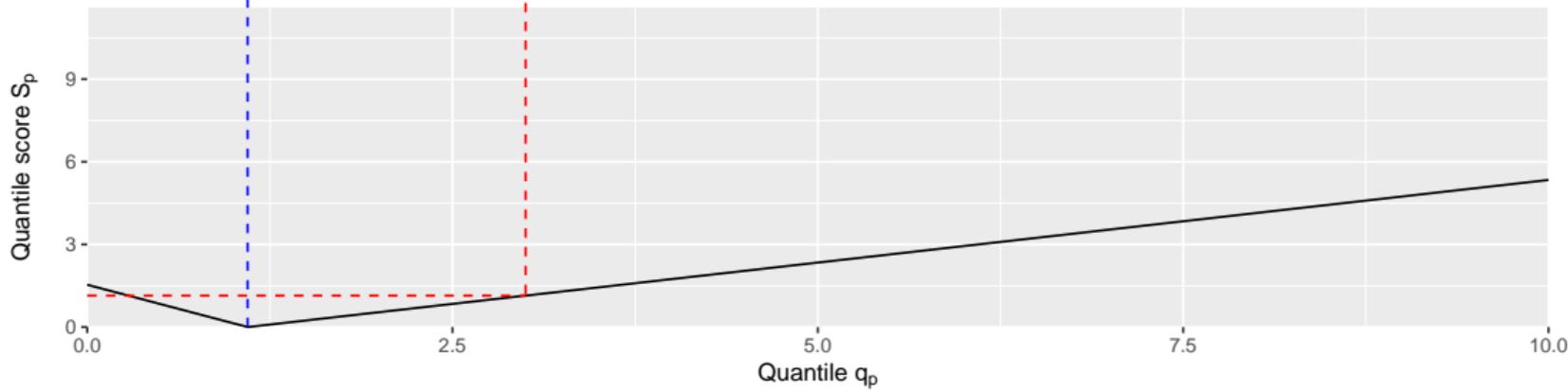
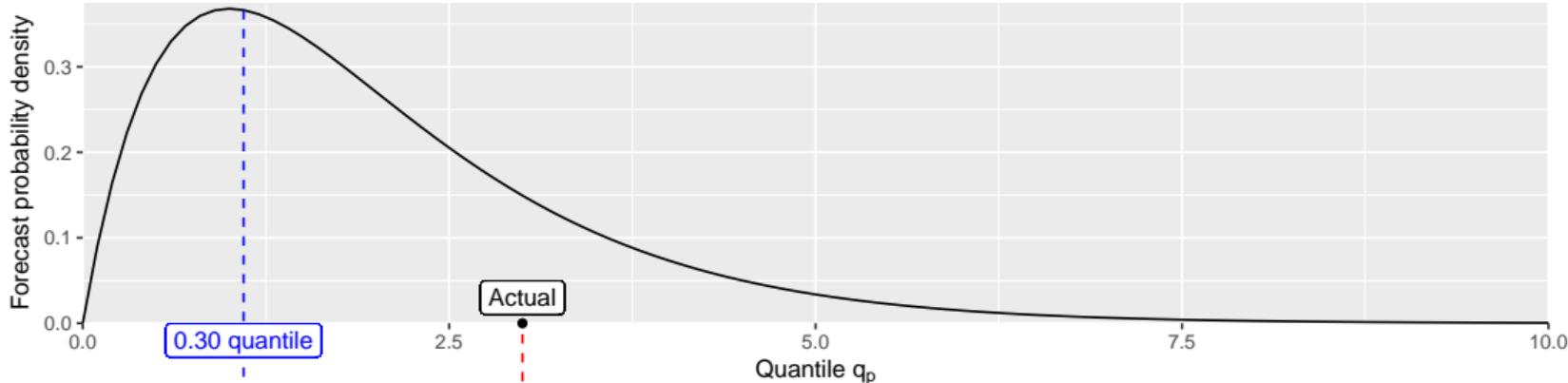
Evaluating probabilistic forecasts



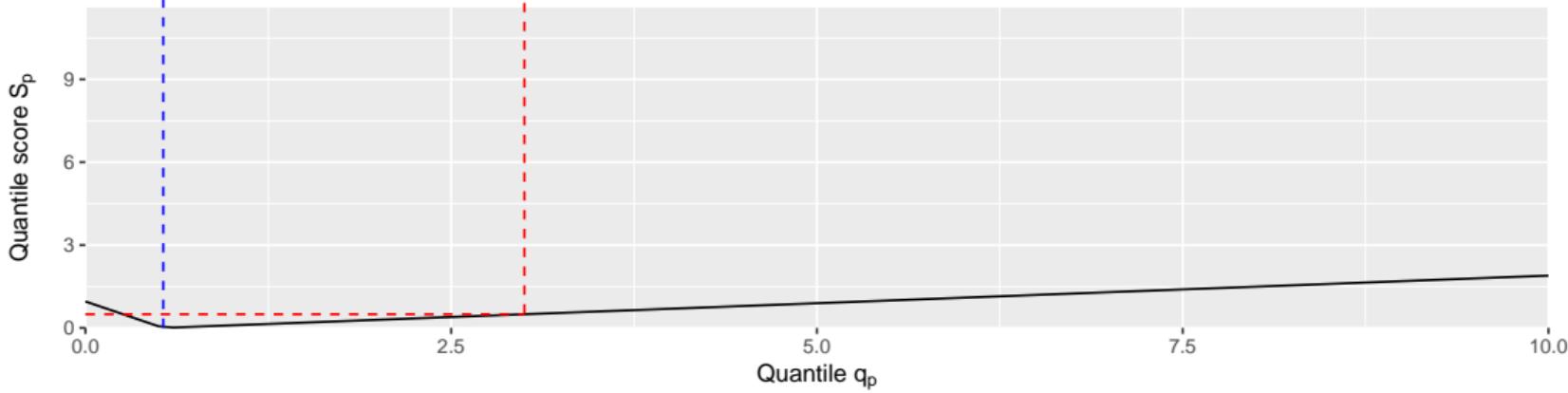
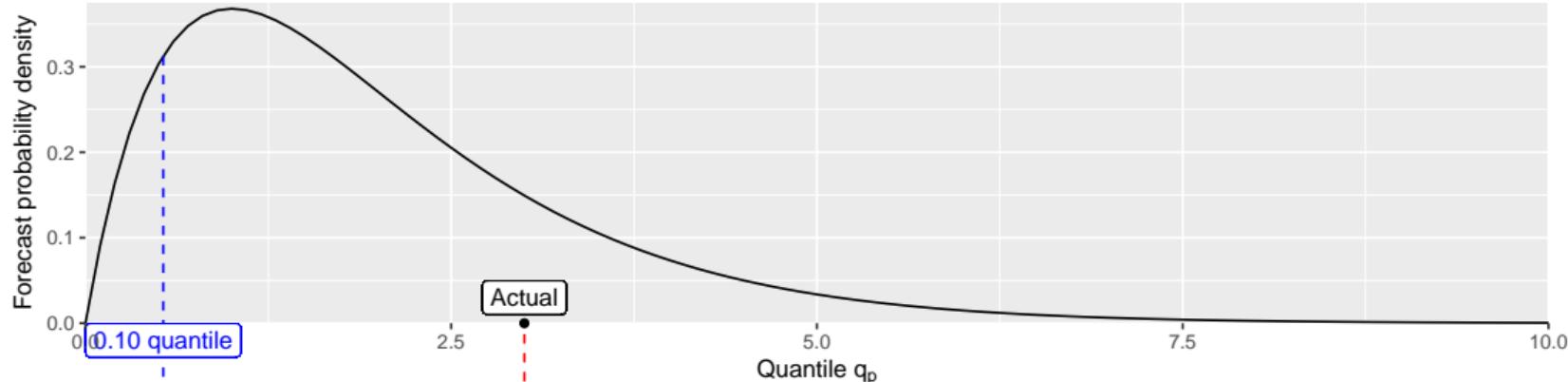
Evaluating probabilistic forecasts



Evaluating probabilistic forecasts

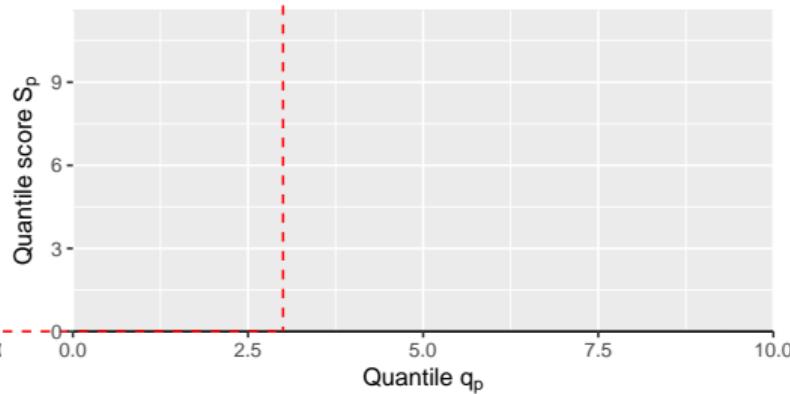
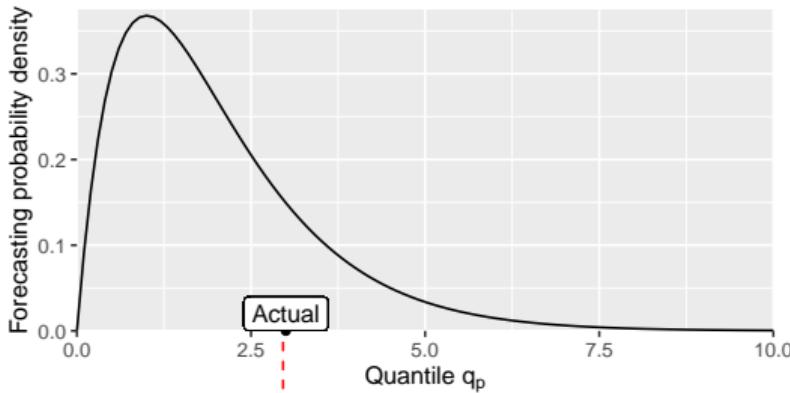
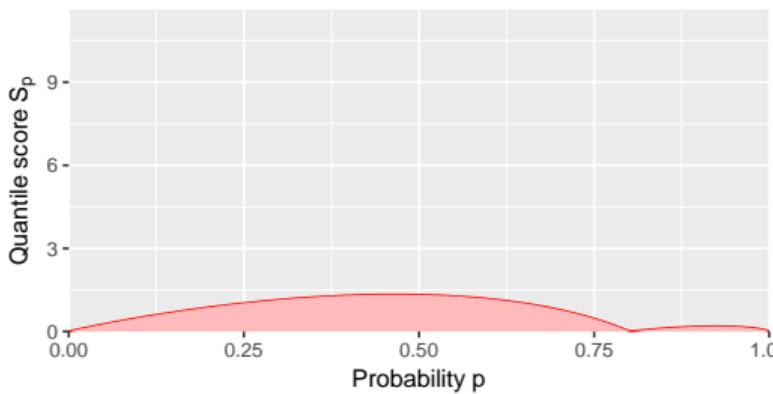


Evaluating probabilistic forecasts

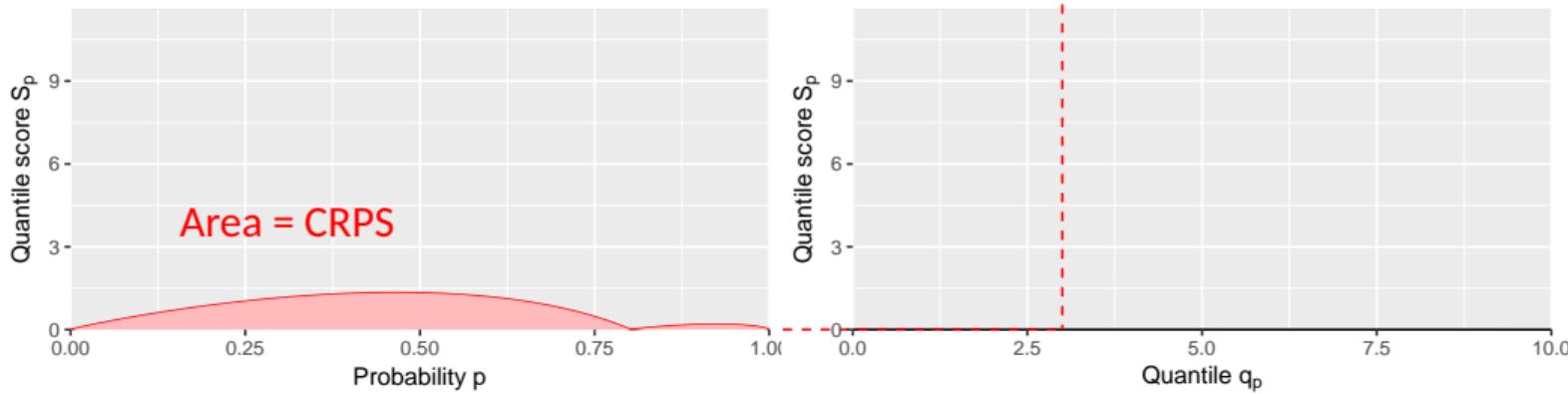
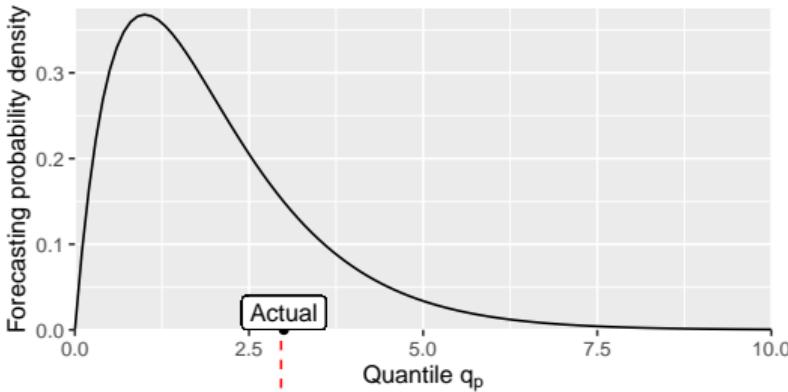


Evaluating probabilistic forecasts

Evaluating probabilistic forecasts



Evaluating probabilistic forecasts



CRPS: Continuous Ranked Probability Score

For weekly forecasts created from 17 September 2020 to 15 June 2021

When should we give up?

- When there is insufficient data?
- When the models give implausible forecasts?
- When the forecast uncertainty is too large to assist decision making?

Outline

- 1 The dark history of forecasting
- 2 What can we forecast?
- 3 Forecasting PBS expenditure
- 4 Forecasting peak electricity demand
- 5 Forecasting COVID-19 cases
- 6 Assessing forecast uncertainty
- 7 The bright future of forecasting

The bright future of forecasting

- What about neural networks and deep learning?

The bright future of forecasting

- What about neural networks and deep learning?
- Will we ever be able to forecast “black swans”?

The bright future of forecasting

- What about neural networks and deep learning?
- Will we ever be able to forecast “black swans”?
- Does more data mean better forecasts?

The bright future of forecasting

- What about neural networks and deep learning?
- Will we ever be able to forecast “black swans”?
- Does more data mean better forecasts?
- Will AI take over forecasting?

The bright future of forecasting

- What about neural networks and deep learning?
- Will we ever be able to forecast “black swans”?
- Does more data mean better forecasts?
- Will AI take over forecasting?
- Are there many jobs for forecasters?

More information

 robjhyndman.com

 [@robjhyndman](https://twitter.com/robjhyndman)

 [@robjhyndman](https://github.com/robjhyndman)

 rob.hyndman@monash.edu

Slides: robjhyndman.com/seminars/anu2022