

# Time Series Analysis & Forecasting Using R

[bit.ly/fable2023](https://bit.ly/fable2023)

## 6. Introduction to forecasting



# Outline

- 1 Statistical forecasting
- 2 Benchmark methods
- 3 Lab Session 11
- 4 Residual diagnostics
- 5 Lab Session 12
- 6 Forecast accuracy measures
- 7 Lab Session 13

# Outline

1 Statistical forecasting

2 Benchmark methods

3 Lab Session 11

4 Residual diagnostics

5 Lab Session 12

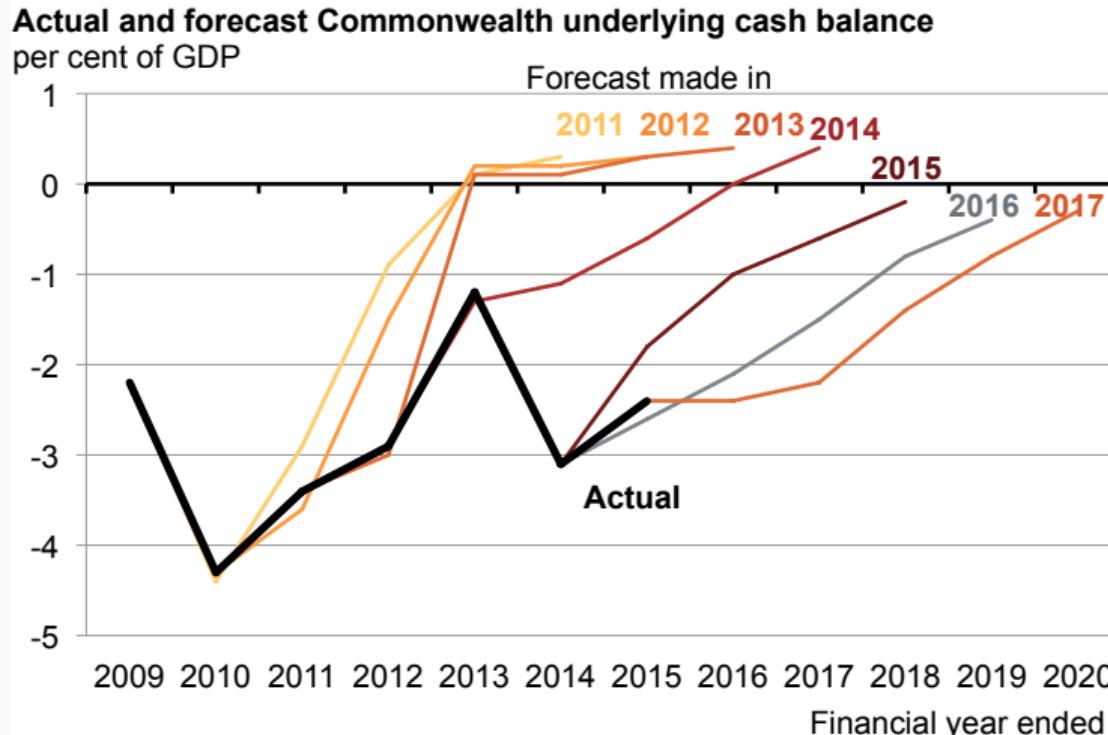
6 Forecast accuracy measures

7 Lab Session 13

# Forecasting is difficult

Commonwealth plans to drift back to surplus  
show the triumph of experience over hope

GRATTAN  
Institute



# What can we forecast?



# What can we forecast?



# What can we forecast?

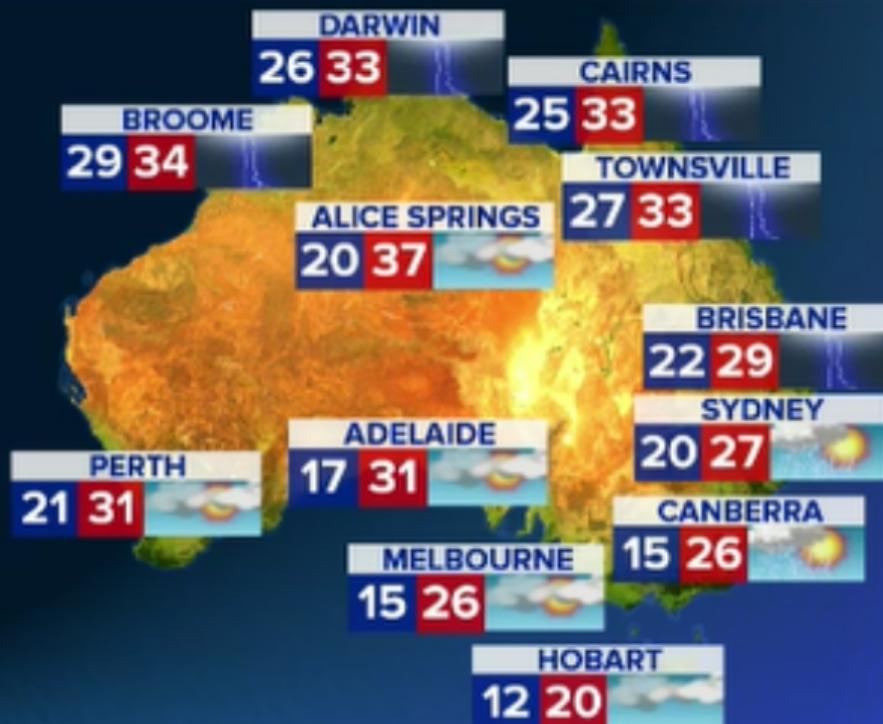


# What can we forecast?



# What can we forecast?

## TOMORROW



# What can we forecast?



# What can we forecast?



# Which is easiest to forecast?

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

# Which is easiest to forecast?

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

# Factors affecting forecastability

Something is easier to forecast if:

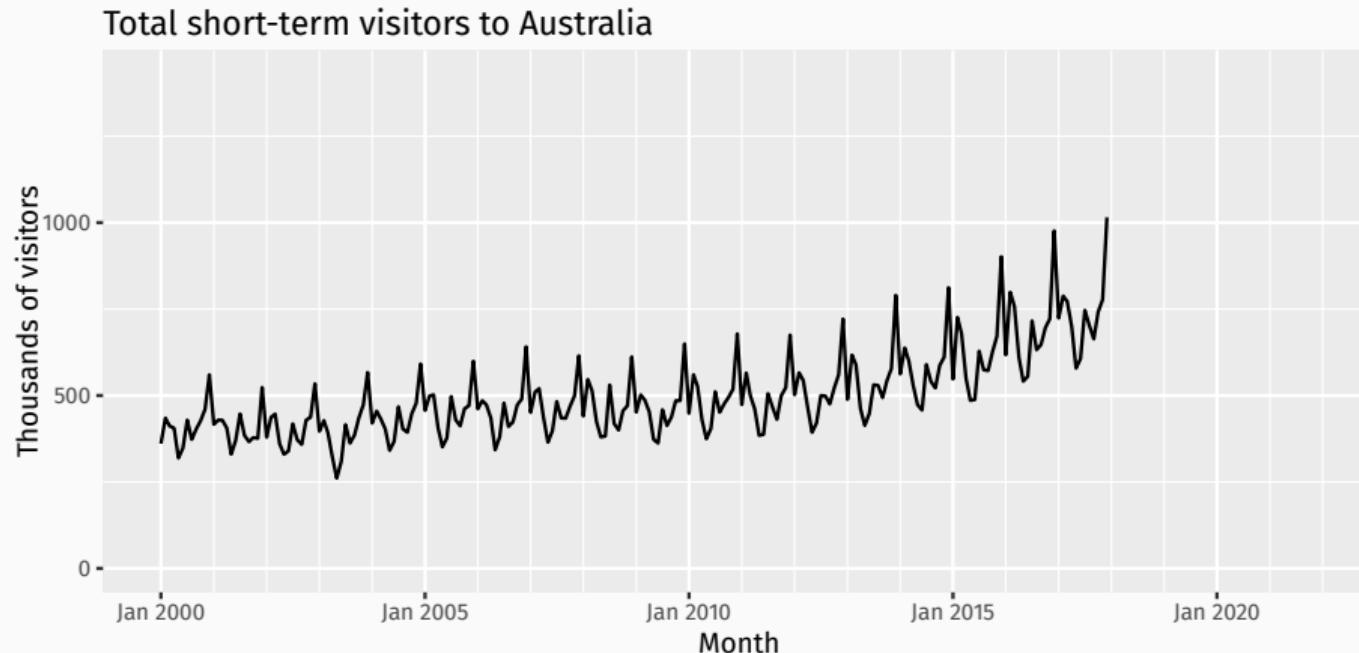
- we have a good understanding of the factors that contribute to it
- there is lots of data available;
- the forecasts cannot affect the thing we are trying to forecast.
- there is relatively low natural/unexplainable random variation.
- the future is somewhat similar to the past

# Random futures

A forecast is an estimate of the probabilities of possible futures.

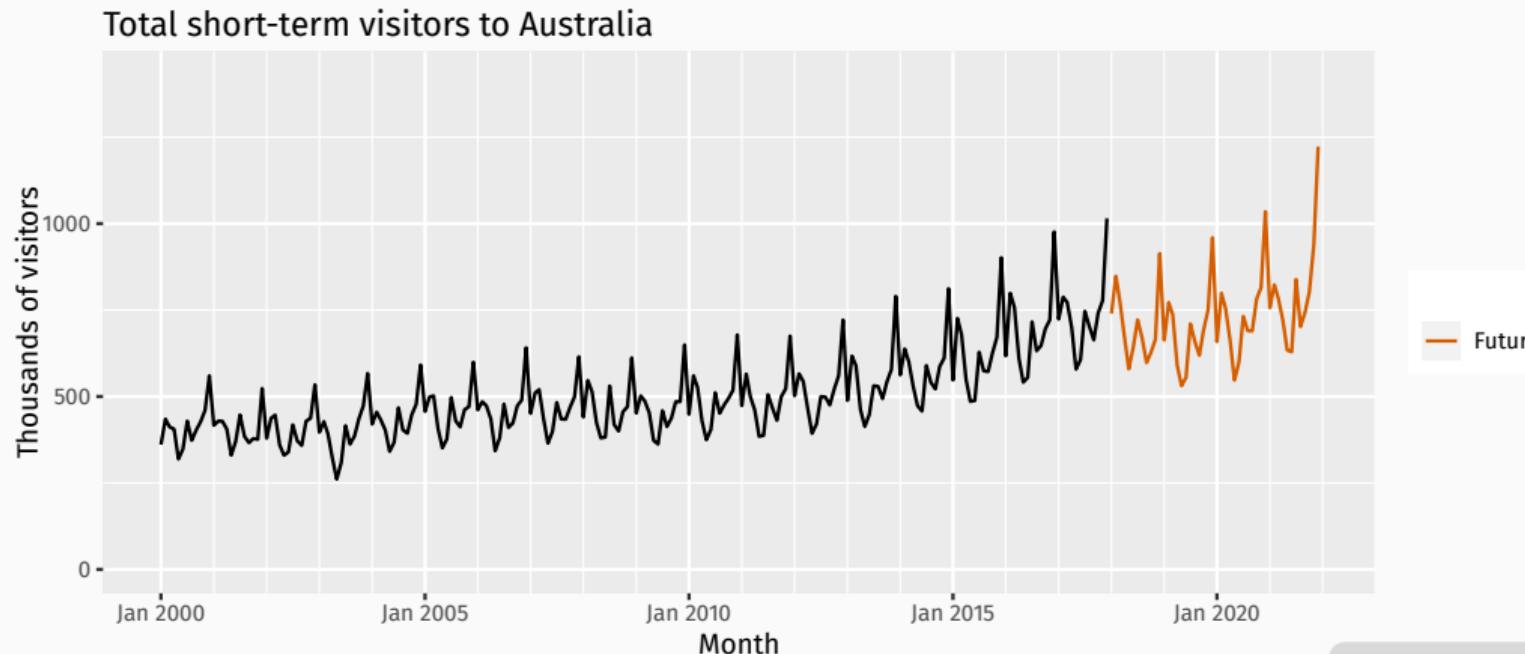
# Random futures

A forecast is an estimate of the probabilities of possible futures.



# Random futures

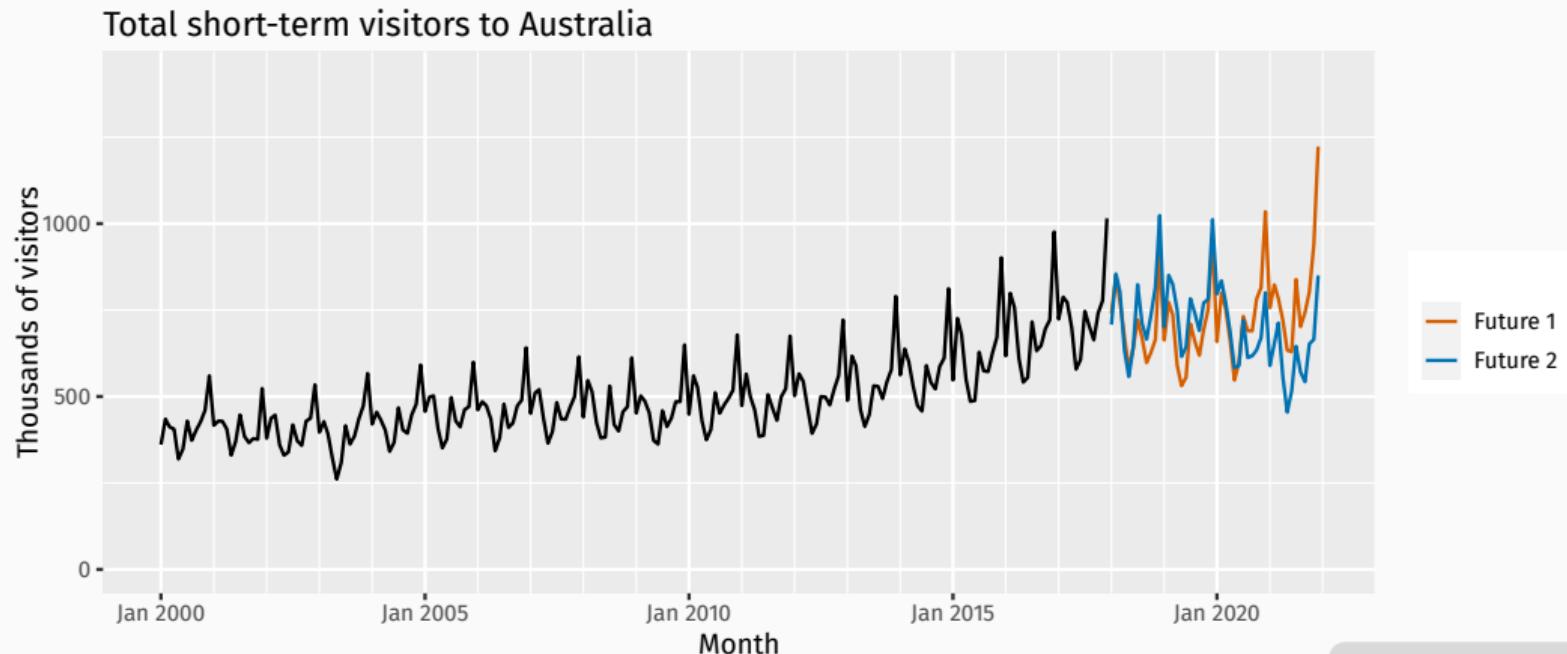
A forecast is an estimate of the probabilities of possible futures.



Simulated futures  
from an ETS model

# Random futures

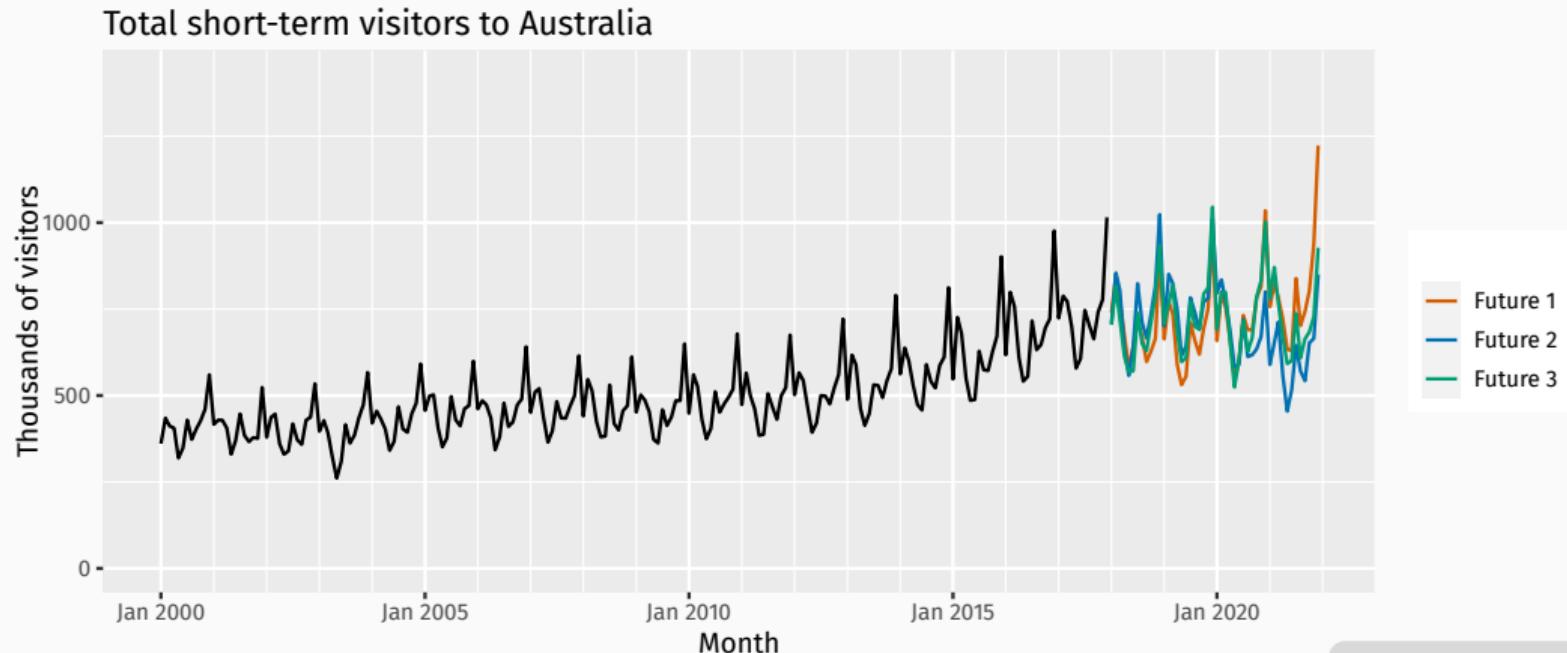
A forecast is an estimate of the probabilities of possible futures.



Simulated futures  
from an ETS model

# Random futures

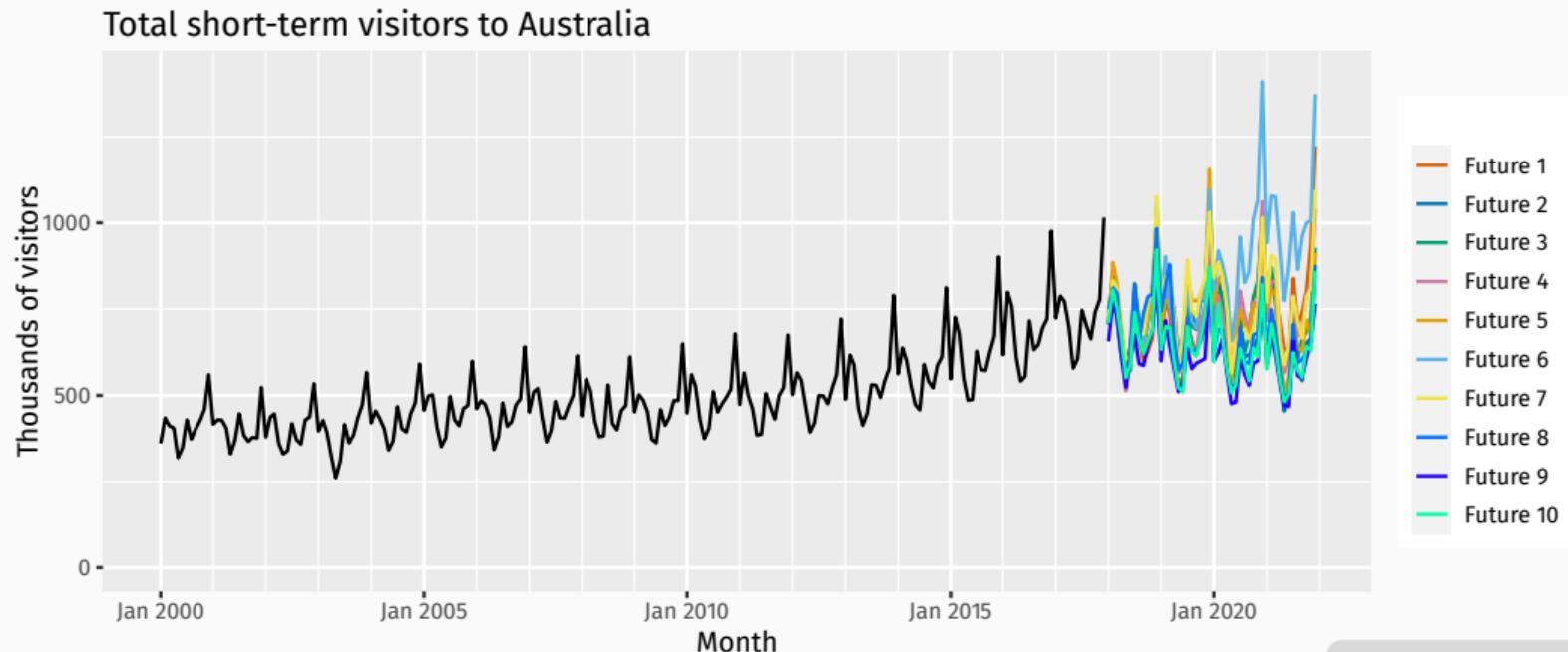
A forecast is an estimate of the probabilities of possible futures.



Simulated futures  
from an ETS model

# Random futures

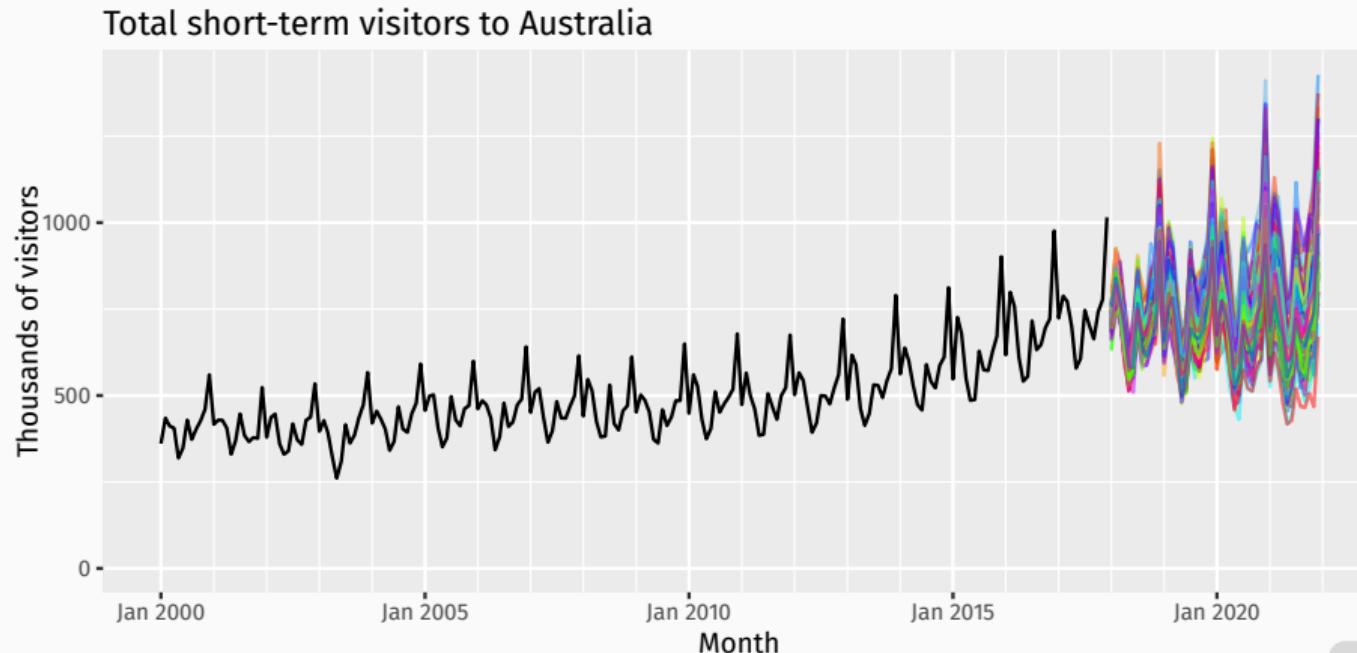
A forecast is an estimate of the probabilities of possible futures.



Simulated futures  
from an ETS model

# Random futures

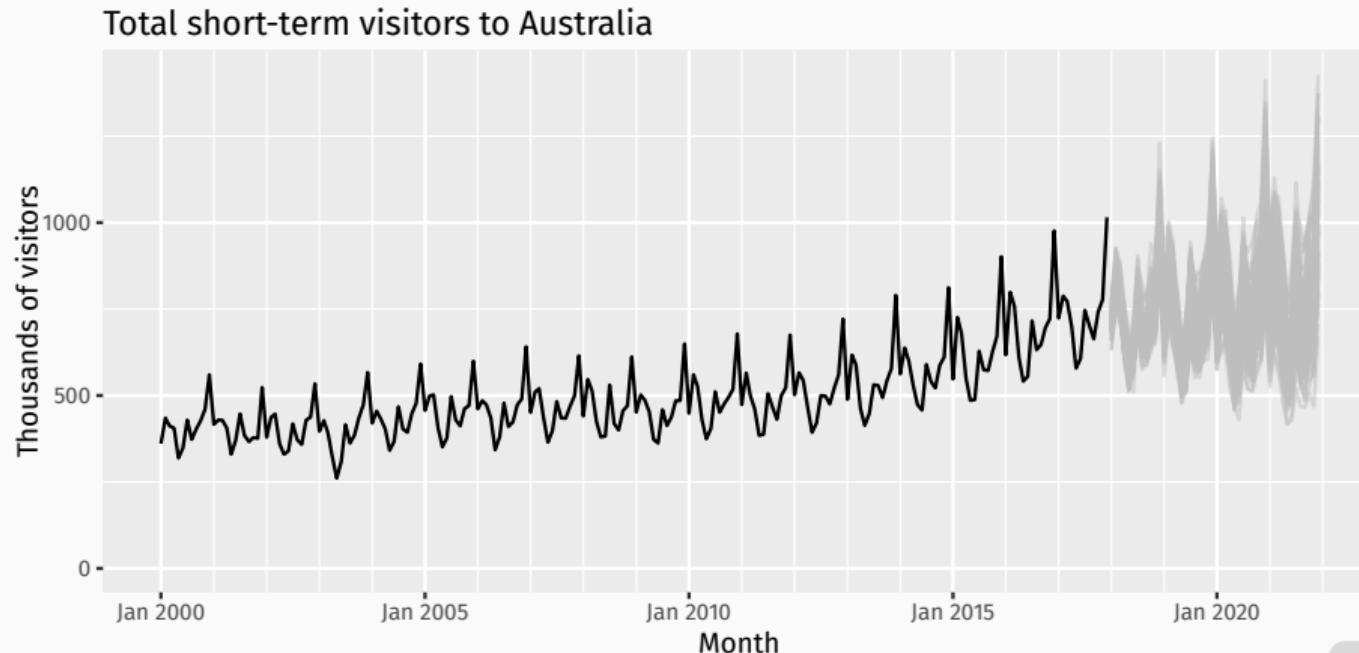
A forecast is an estimate of the probabilities of possible futures.



Simulated futures  
from an ETS model

# Random futures

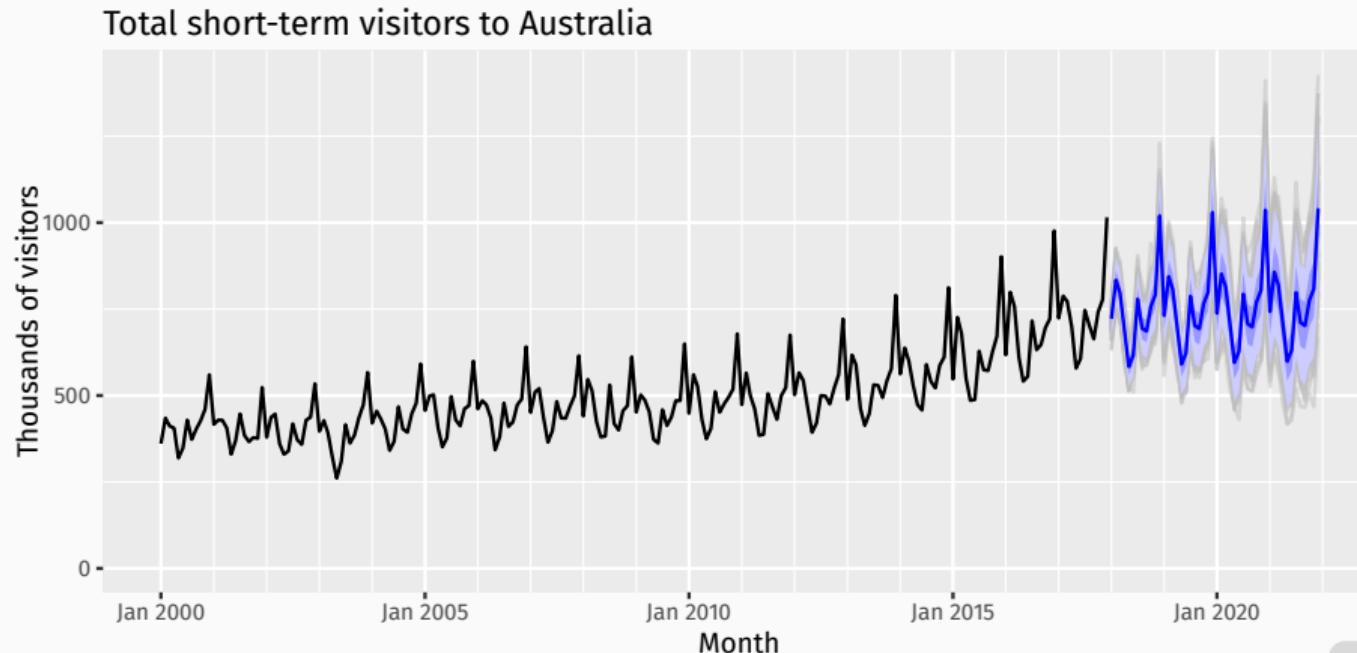
A forecast is an estimate of the probabilities of possible futures.



Simulated futures  
from an ETS model

# Random futures

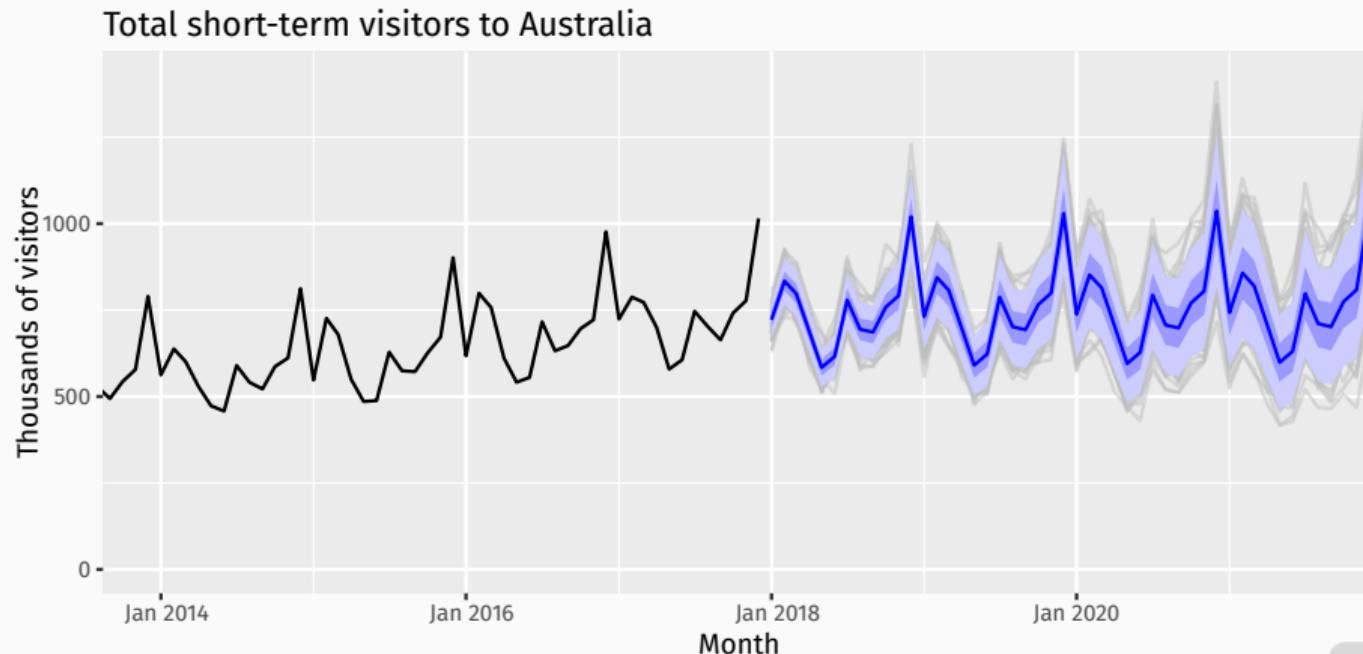
A forecast is an estimate of the probabilities of possible futures.



Simulated futures  
from an ETS model

# Random futures

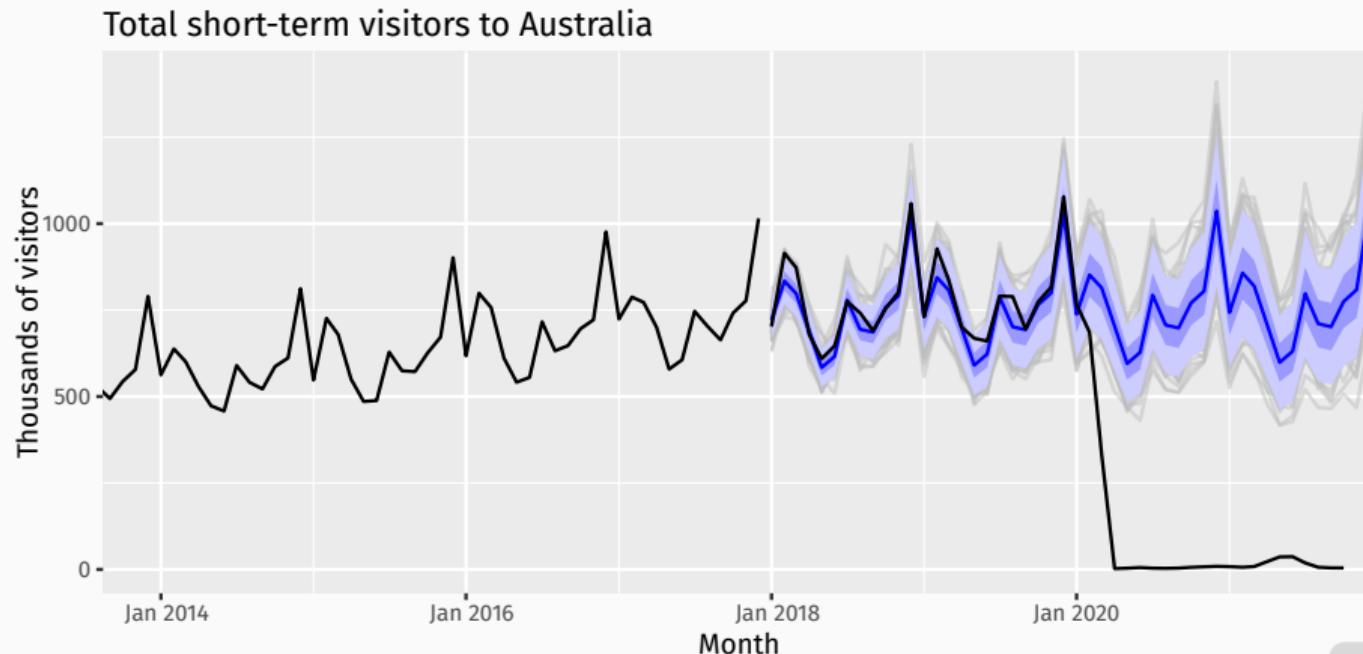
A forecast is an estimate of the probabilities of possible futures.



Simulated futures  
from an ETS model

# Random futures

A forecast is an estimate of the probabilities of possible futures.

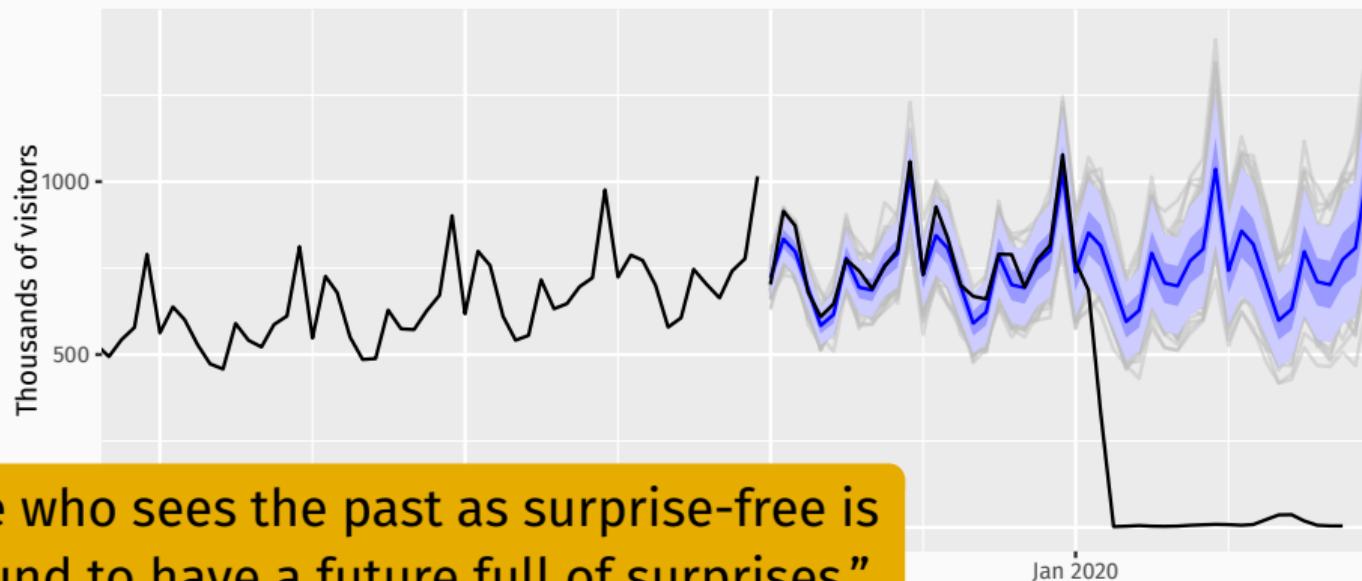


Simulated futures  
from an ETS model

# Random futures

A forecast is an estimate of the probabilities of possible futures.

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

# Statistical forecasting

- Thing to be forecast:  $y_{T+h}$ .
- What we know:  $y_1, \dots, y_T$ .
- Forecast distribution:  $y_{T+h|t} = y_{T+h} \mid \{y_1, y_2, \dots, y_T\}$ .
- Point forecast:  $\hat{y}_{T+h|T} = E[y_{T+h} \mid y_1, \dots, y_T]$ .
- Forecast variance:  $\text{Var}[y_t \mid y_1, \dots, y_T]$
- Prediction interval is a range of values of  $y_{T+h}$  with high probability.

# Outline

1 Statistical forecasting

2 Benchmark methods

3 Lab Session 11

4 Residual diagnostics

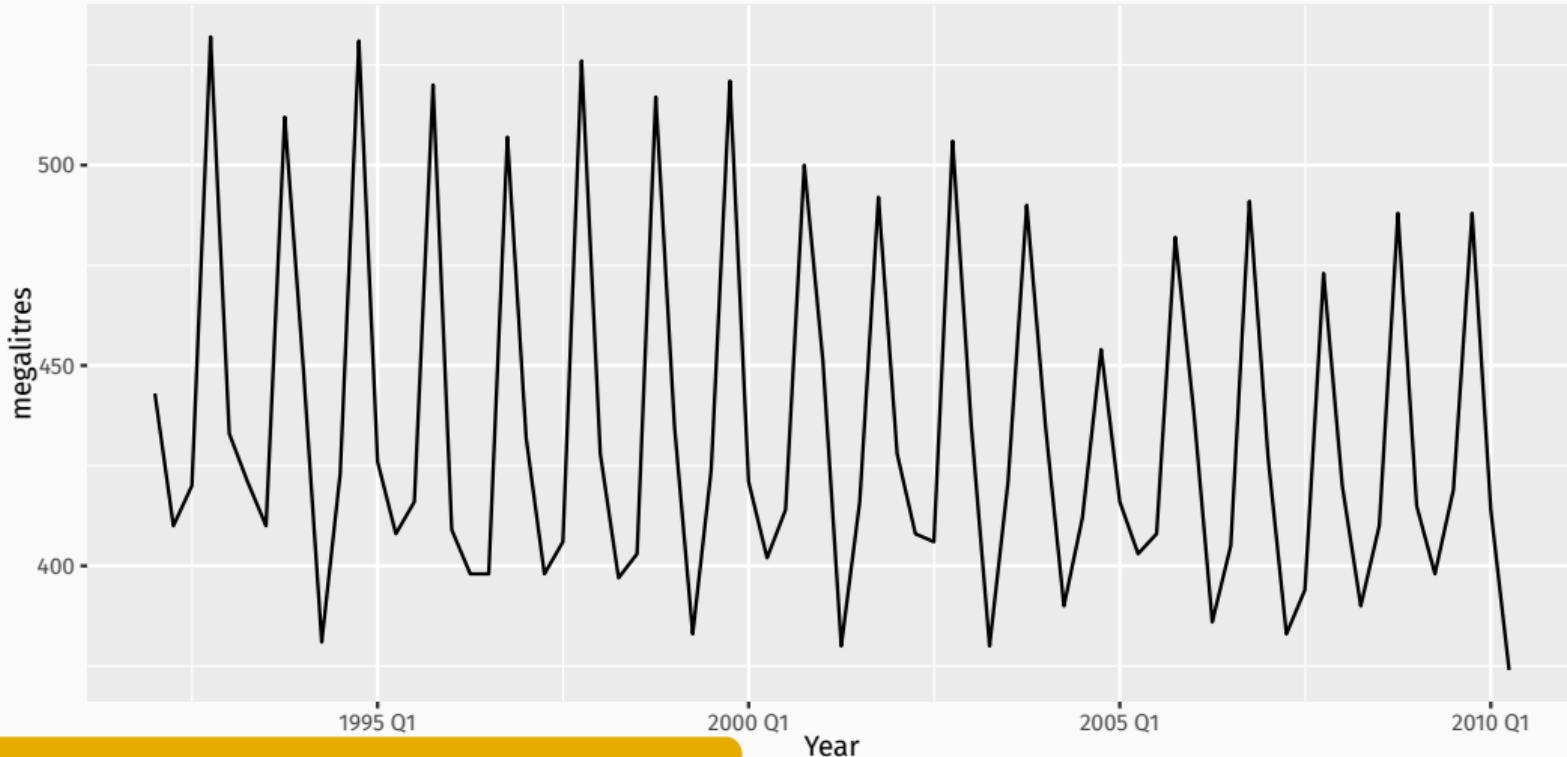
5 Lab Session 12

6 Forecast accuracy measures

7 Lab Session 13

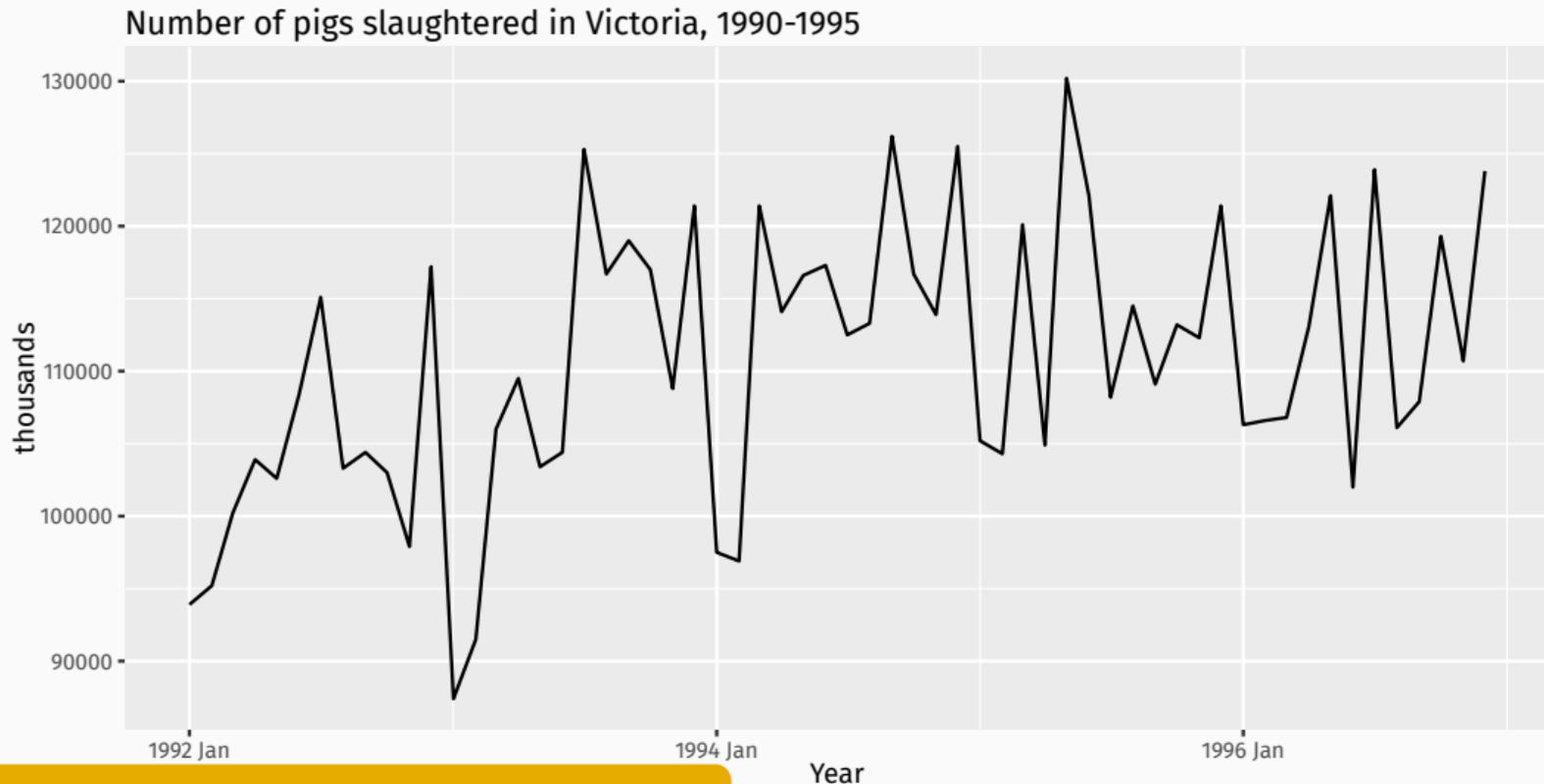
# Some simple forecasting methods

Australian quarterly beer production



How would you forecast these series?

# Some simple forecasting methods



How would you forecast these series?

# Some simple forecasting methods

Facebook closing stock price in 2018

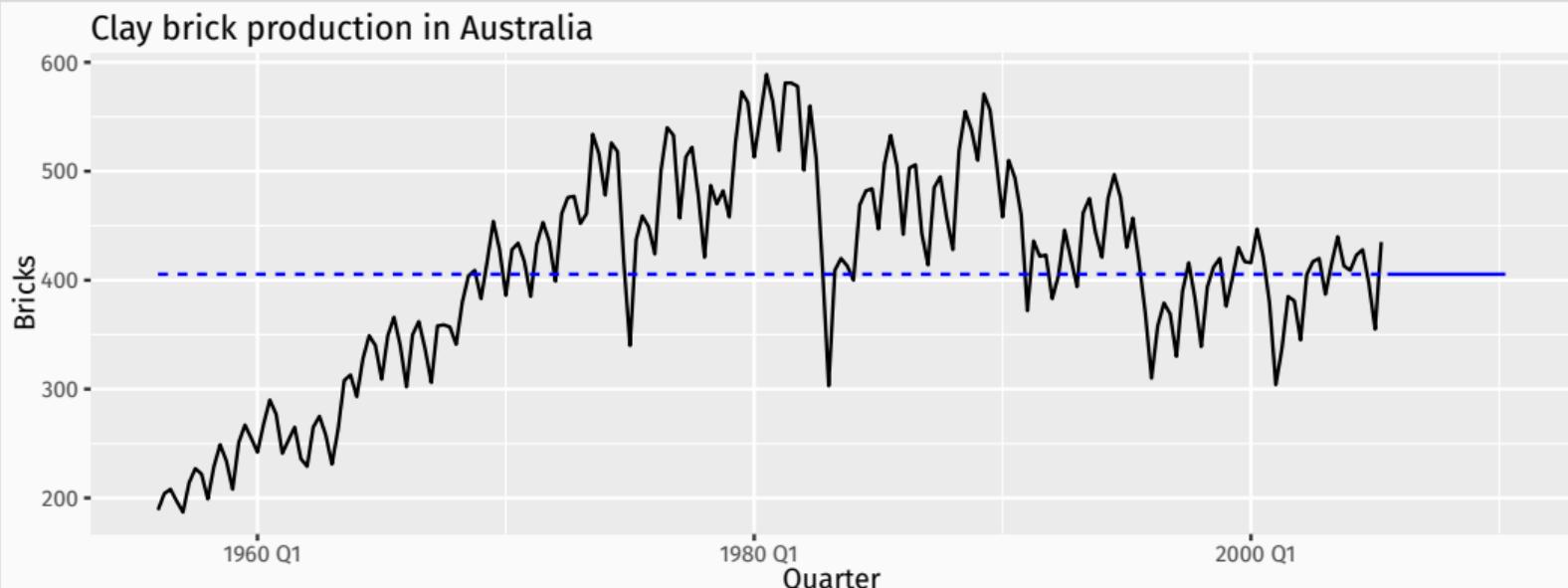


How would you forecast these series?

# Some simple forecasting methods

## MEAN(y): Average method

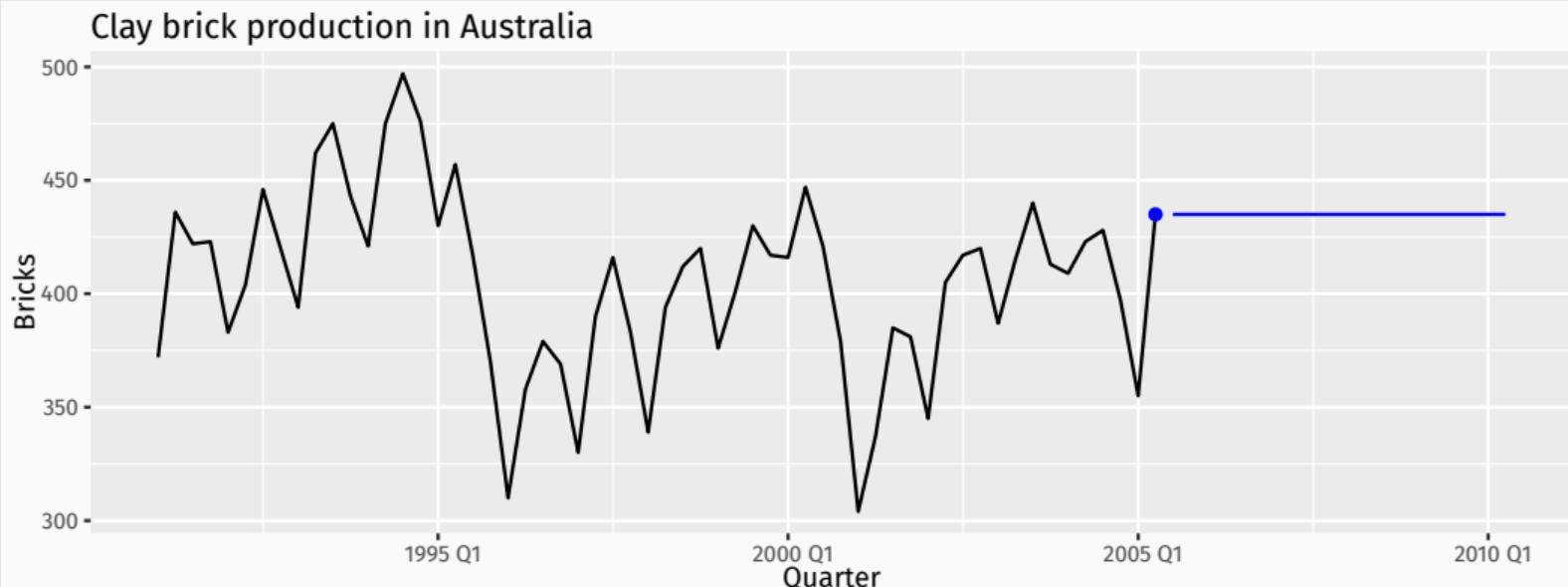
- Forecast of all future values is equal to mean of historical data  $\{y_1, \dots, y_T\}$ .
  - Forecasts:  $\hat{y}_{T+h|T} = \bar{y} = (y_1 + \dots + y_T)/T$



# Some simple forecasting methods

## NAIVE( $y$ ): Naïve method

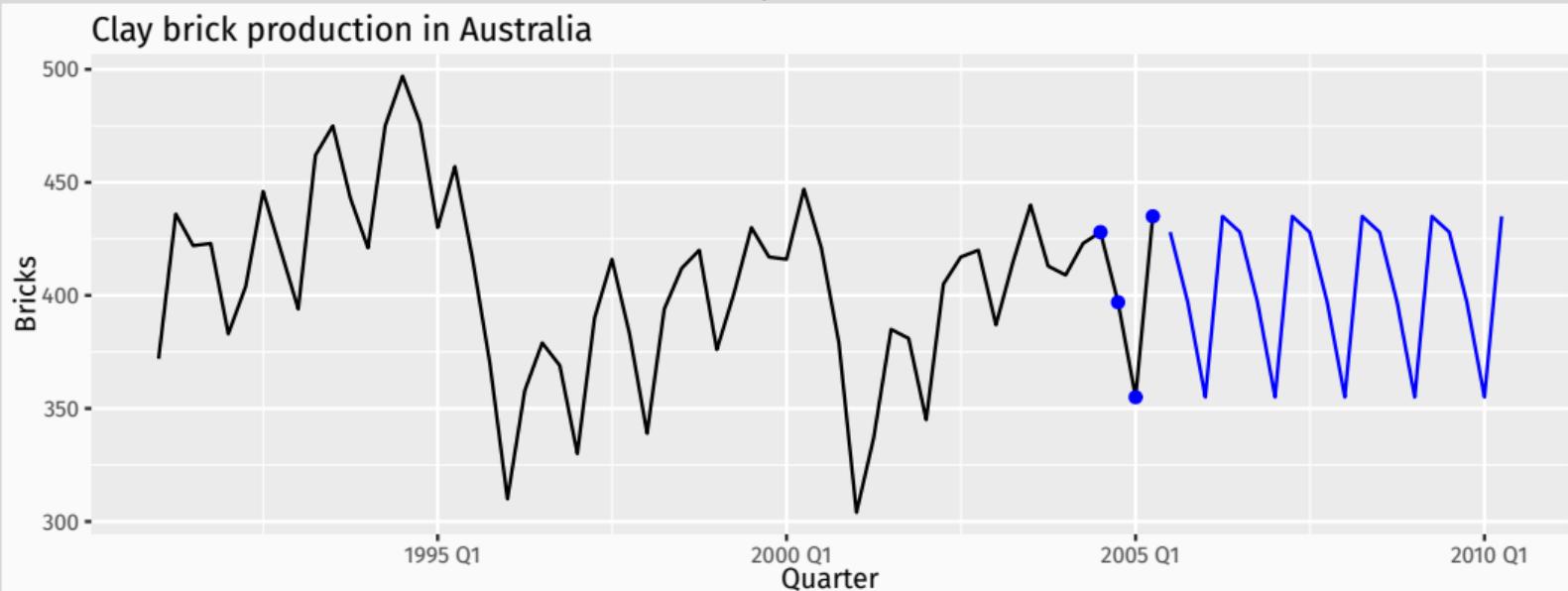
- Forecasts equal to last observed value.
- Forecasts:  $\hat{y}_{T+h|T} = y_T$ .
- Consequence of efficient market hypothesis.



# Some simple forecasting methods

## SNAIVE( $y \sim \text{lag}(m)$ ): Seasonal naïve method

- Forecasts equal to last value from same season.
- Forecasts:  $\hat{y}_{T+h|T} = y_{T+h-m(k+1)}$ , where  $m$  = seasonal period and  $k$  is the integer part of  $(h - 1)/m$ .



# Some simple forecasting methods

## RW(y ~ drift()): Drift method

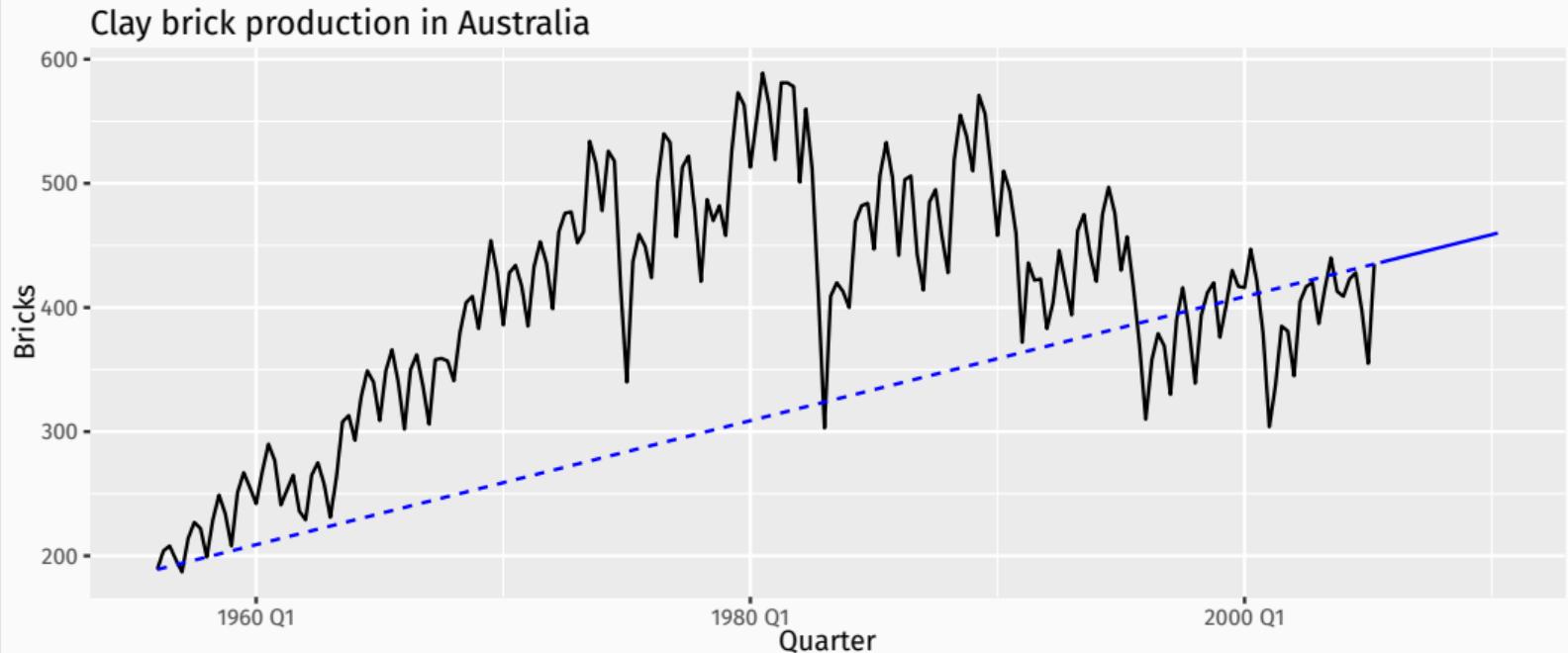
- Forecasts equal to last value plus average change.
- Forecasts:

$$\begin{aligned}\hat{y}_{T+h|T} &= y_T + \frac{h}{T-1} \sum_{t=2}^T (y_t - y_{t-1}) \\ &= y_T + \frac{h}{T-1} (y_T - y_1).\end{aligned}$$

- Equivalent to extrapolating a line drawn between first and last observations.

# Some simple forecasting methods

## Drift method



# Model fitting

The `model()` function trains models to data.

```
brick_fit <- aus_production |>  
  filter(!is.na(Bricks)) |>  
  model(  
    `Seasonal_naïve` = SNAIVE(Bricks),  
    `Naïve` = NAIVE(Bricks),  
    Drift = RW(Bricks ~ drift()),  
    Mean = MEAN(Bricks)  
)
```

```
# A mable: 1 x 4  
  Seasonal_naïve   Naïve          Drift      Mean  
  <model> <model>       <model> <model>  
1     <SNAIVE> <NAIVE> <RW w/ drift> <MEAN>
```

A `mable` is a model table, each cell corresponds to a fitted model.

# Producing forecasts

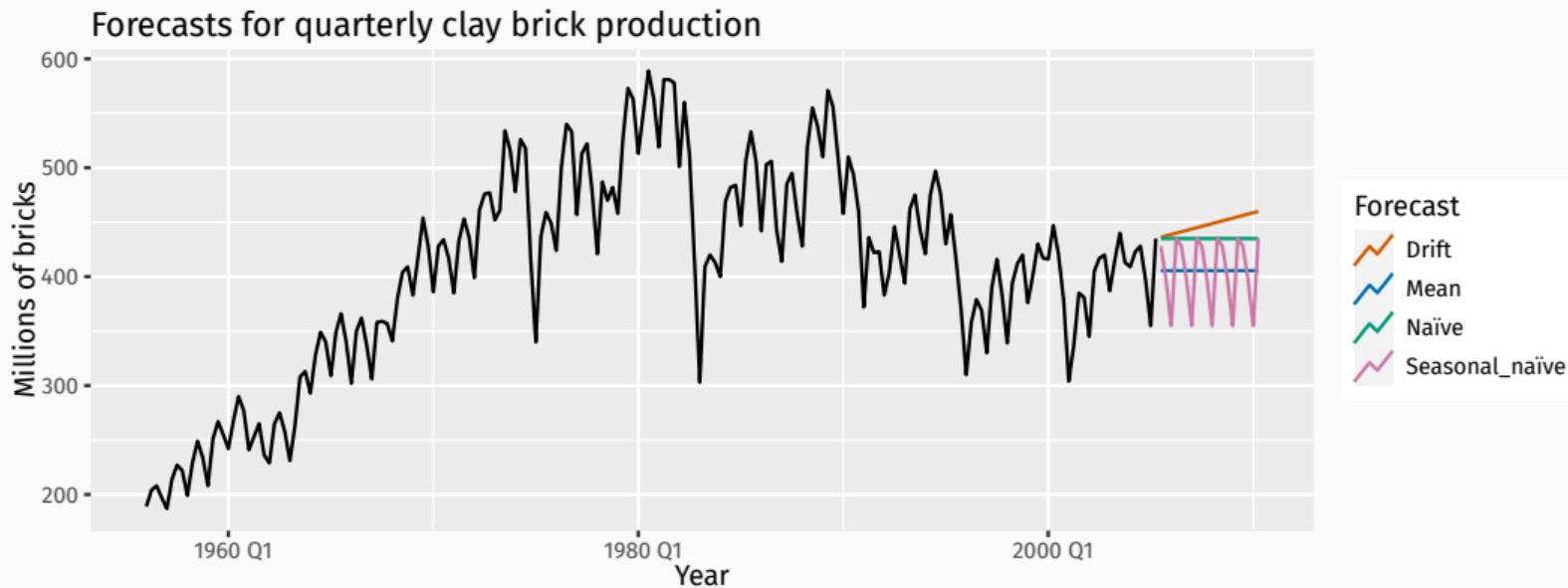
```
brick_fc <- brick_fit |>  
  forecast(h = "5 years")
```

```
# A fable: 80 x 4 [1Q]  
# Key:     .model [4]  
  
.model          Quarter      Bricks .mean  
<chr>           <qtr>       <dist> <dbl>  
1 Seasonal_naïve 2005 Q3 N(428, 2336)    428  
2 Seasonal_naïve 2005 Q4 N(397, 2336)    397  
3 Seasonal_naïve 2006 Q1 N(355, 2336)    355  
4 Seasonal_naïve 2006 Q2 N(435, 2336)    435  
# i 76 more rows
```

A fable is a forecast table with point forecasts and distributions.

# Visualising forecasts

```
brick_fc |>  
  autoplot(aus_production, level = NULL) +  
  labs(title = "Forecasts for quarterly clay brick production",  
       x = "Year", y = "Millions of bricks") +  
  guides(colour = guide_legend(title = "Forecast"))
```



# Prediction intervals

```
brick_fc |>  
  hilo(level = c(50, 75))
```

#	Key:	.model	Quarter	Bricks	.mean	`50%`	`75%`
		.model	<chr>	<qtr>	<dist>	<dbl>	<hilo>
1	Seasonal_naïve	2005 Q3	N(428, 2336)	428	[395, 461]	50 [372, 484]	75
2	Seasonal_naïve	2005 Q4	N(397, 2336)	397	[364, 430]	50 [341, 453]	75
3	Seasonal_naïve	2006 Q1	N(355, 2336)	355	[322, 388]	50 [299, 411]	75
4	Seasonal_naïve	2006 Q2	N(435, 2336)	435	[402, 468]	50 [379, 491]	75
5	Seasonal_naïve	2006 Q3	N(428, 4672)	428	[382, 474]	50 [349, 507]	75
6	Seasonal_naïve	2006 Q4	N(397, 4672)	397	[351, 443]	50 [318, 476]	75
7	Seasonal_naïve	2007 Q1	N(355, 4672)	355	[309, 401]	50 [276, 434]	75
8	Seasonal_naïve	2007 Q2	N(435, 4672)	435	[389, 481]	50 [356, 514]	75
9	Seasonal_naïve	2007 Q3	N(428, 7008)	428	[372, 484]	50 [332, 524]	75

# Prediction intervals

```
brick_fc |>  
  hilo(level = c(50, 75)) |>  
  mutate(lower = `50%`$lower, upper = `50%`$upper)
```

# A tsibble: 80 x 8 [1Q]	# Key: .model [4]	.model	Quarter	Bricks	.mean	`50%`	`75%`	lower	upper
		<chr>	<qtr>	<dist>	<dbl>	<hilo>	<hilo>	<dbl>	<dbl>
1	Seasonal_naïve	2005 Q3	N(428, 2336)	428	[395, 461]	50	[372, 484]	75	395.
2	Seasonal_naïve	2005 Q4	N(397, 2336)	397	[364, 430]	50	[341, 453]	75	364.
3	Seasonal_naïve	2006 Q1	N(355, 2336)	355	[322, 388]	50	[299, 411]	75	322.
4	Seasonal_naïve	2006 Q2	N(435, 2336)	435	[402, 468]	50	[379, 491]	75	402.
5	Seasonal_naïve	2006 Q3	N(428, 4672)	428	[382, 474]	50	[349, 507]	75	382.
6	Seasonal_naïve	2006 Q4	N(397, 4672)	397	[351, 443]	50	[318, 476]	75	351.
7	Seasonal_naïve	2007 Q1	N(355, 4672)	355	[309, 401]	50	[276, 434]	75	309.
8	Seasonal_naïve	2007 Q2	N(435, 4672)	435	[389, 481]	50	[356, 514]	75	389.
9	Seasonal_naïve	2007 Q3	N(428, 5600)	428	[378, 478]	50	[328, 524]	75	378.
10	Seasonal_naïve	2007 Q4	N(397, 5600)	397	[351, 443]	50	[318, 476]	75	351.
11	Seasonal_naïve	2008 Q1	N(355, 5600)	355	[309, 401]	50	[276, 434]	75	309.
12	Seasonal_naïve	2008 Q2	N(435, 5600)	435	[389, 481]	50	[356, 514]	75	389.
13	Seasonal_naïve	2008 Q3	N(428, 6560)	428	[378, 478]	50	[328, 524]	75	378.
14	Seasonal_naïve	2008 Q4	N(397, 6560)	397	[351, 443]	50	[318, 476]	75	351.
15	Seasonal_naïve	2009 Q1	N(355, 6560)	355	[309, 401]	50	[276, 434]	75	309.
16	Seasonal_naïve	2009 Q2	N(435, 6560)	435	[389, 481]	50	[356, 514]	75	389.
17	Seasonal_naïve	2009 Q3	N(428, 7560)	428	[378, 478]	50	[328, 524]	75	378.
18	Seasonal_naïve	2009 Q4	N(397, 7560)	397	[351, 443]	50	[318, 476]	75	351.
19	Seasonal_naïve	2010 Q1	N(355, 7560)	355	[309, 401]	50	[276, 434]	75	309.
20	Seasonal_naïve	2010 Q2	N(435, 7560)	435	[389, 481]	50	[356, 514]	75	389.
21	Seasonal_naïve	2010 Q3	N(428, 8560)	428	[378, 478]	50	[328, 524]	75	378.
22	Seasonal_naïve	2010 Q4	N(397, 8560)	397	[351, 443]	50	[318, 476]	75	351.
23	Seasonal_naïve	2011 Q1	N(355, 8560)	355	[309, 401]	50	[276, 434]	75	309.
24	Seasonal_naïve	2011 Q2	N(435, 8560)	435	[389, 481]	50	[356, 514]	75	389.
25	Seasonal_naïve	2011 Q3	N(428, 9560)	428	[378, 478]	50	[328, 524]	75	378.
26	Seasonal_naïve	2011 Q4	N(397, 9560)	397	[351, 443]	50	[318, 476]	75	351.
27	Seasonal_naïve	2012 Q1	N(355, 9560)	355	[309, 401]	50	[276, 434]	75	309.
28	Seasonal_naïve	2012 Q2	N(435, 9560)	435	[389, 481]	50	[356, 514]	75	389.
29	Seasonal_naïve	2012 Q3	N(428, 10560)	428	[378, 478]	50	[328, 524]	75	378.
30	Seasonal_naïve	2012 Q4	N(397, 10560)	397	[351, 443]	50	[318, 476]	75	351.
31	Seasonal_naïve	2013 Q1	N(355, 10560)	355	[309, 401]	50	[276, 434]	75	309.
32	Seasonal_naïve	2013 Q2	N(435, 10560)	435	[389, 481]	50	[356, 514]	75	389.
33	Seasonal_naïve	2013 Q3	N(428, 11560)	428	[378, 478]	50	[328, 524]	75	378.
34	Seasonal_naïve	2013 Q4	N(397, 11560)	397	[351, 443]	50	[318, 476]	75	351.
35	Seasonal_naïve	2014 Q1	N(355, 11560)	355	[309, 401]	50	[276, 434]	75	309.
36	Seasonal_naïve	2014 Q2	N(435, 11560)	435	[389, 481]	50	[356, 514]	75	389.
37	Seasonal_naïve	2014 Q3	N(428, 12560)	428	[378, 478]	50	[328, 524]	75	378.
38	Seasonal_naïve	2014 Q4	N(397, 12560)	397	[351, 443]	50	[318, 476]	75	351.
39	Seasonal_naïve	2015 Q1	N(355, 12560)	355	[309, 401]	50	[276, 434]	75	309.
40	Seasonal_naïve	2015 Q2	N(435, 12560)	435	[389, 481]	50	[356, 514]	75	389.
41	Seasonal_naïve	2015 Q3	N(428, 13560)	428	[378, 478]	50	[328, 524]	75	378.
42	Seasonal_naïve	2015 Q4	N(397, 13560)	397	[351, 443]	50	[318, 476]	75	351.
43	Seasonal_naïve	2016 Q1	N(355, 13560)	355	[309, 401]	50	[276, 434]	75	309.
44	Seasonal_naïve	2016 Q2	N(435, 13560)	435	[389, 481]	50	[356, 514]	75	389.
45	Seasonal_naïve	2016 Q3	N(428, 14560)	428	[378, 478]	50	[328, 524]	75	378.
46	Seasonal_naïve	2016 Q4	N(397, 14560)	397	[351, 443]	50	[318, 476]	75	351.
47	Seasonal_naïve	2017 Q1	N(355, 14560)	355	[309, 401]	50	[276, 434]	75	309.
48	Seasonal_naïve	2017 Q2	N(435, 14560)	435	[389, 481]	50	[356, 514]	75	389.
49	Seasonal_naïve	2017 Q3	N(428, 15560)	428	[378, 478]	50	[328, 524]	75	378.
50	Seasonal_naïve	2017 Q4	N(397, 15560)	397	[351, 443]	50	[318, 476]	75	351.
51	Seasonal_naïve	2018 Q1	N(355, 15560)	355	[309, 401]	50	[276, 434]	75	309.
52	Seasonal_naïve	2018 Q2	N(435, 15560)	435	[389, 481]	50	[356, 514]	75	389.
53	Seasonal_naïve	2018 Q3	N(428, 16560)	428	[378, 478]	50	[328, 524]	75	378.
54	Seasonal_naïve	2018 Q4	N(397, 16560)	397	[351, 443]	50	[318, 476]	75	351.
55	Seasonal_naïve	2019 Q1	N(355, 16560)	355	[309, 401]	50	[276, 434]	75	309.
56	Seasonal_naïve	2019 Q2	N(435, 16560)	435	[389, 481]	50	[356, 514]	75	389.
57	Seasonal_naïve	2019 Q3	N(428, 17560)	428	[378, 478]	50	[328, 524]	75	378.
58	Seasonal_naïve	2019 Q4	N(397, 17560)	397	[351, 443]	50	[318, 476]	75	351.
59	Seasonal_naïve	2020 Q1	N(355, 17560)	355	[309, 401]	50	[276, 434]	75	309.
60	Seasonal_naïve	2020 Q2	N(435, 17560)	435	[389, 481]	50	[356, 514]	75	389.
61	Seasonal_naïve	2020 Q3	N(428, 18560)	428	[378, 478]	50	[328, 524]	75	378.
62	Seasonal_naïve	2020 Q4	N(397, 18560)	397	[351, 443]	50	[318, 476]	75	351.
63	Seasonal_naïve	2021 Q1	N(355, 18560)	355	[309, 401]	50	[276, 434]	75	309.
64	Seasonal_naïve	2021 Q2	N(435, 18560)	435	[389, 481]	50	[356, 514]	75	389.
65	Seasonal_naïve	2021 Q3	N(428, 19560)	428	[378, 478]	50	[328, 524]	75	378.
66	Seasonal_naïve	2021 Q4	N(397, 19560)	397	[351, 443]	50	[318, 476]	75	351.
67	Seasonal_naïve	2022 Q1	N(355, 19560)	355	[309, 401]	50	[276, 434]	75	309.
68	Seasonal_naïve	2022 Q2	N(435, 19560)	435	[389, 481]	50	[356, 514]	75	389.
69	Seasonal_naïve	2022 Q3	N(428, 20560)	428	[378, 478]	50	[328, 524]	75	378.
70	Seasonal_naïve	2022 Q4	N(397, 20560)	397	[351, 443]	50	[318, 476]	75	351.
71	Seasonal_naïve	2023 Q1	N(355, 20560)	355	[309, 401]	50	[276, 434]	75	309.
72	Seasonal_naïve	2023 Q2	N(435, 20560)	435	[389, 481]	50	[356, 514]	75	389.
73	Seasonal_naïve	2023 Q3	N(428, 21560)	428	[378, 478]	50	[328, 524]	75	378.
74	Seasonal_naïve	2023 Q4	N(397, 21560)	397	[351, 443]	50	[318, 476]	75	351.
75	Seasonal_naïve	2024 Q1	N(355, 21560)	355	[309, 401]	50	[276, 434]	75	309.
76	Seasonal_naïve	2024 Q2	N(435, 21560)	435	[389, 481]	50	[356, 514]	75	389.
77	Seasonal_naïve	2024 Q3	N(428, 22560)	428	[378, 478]	50	[328, 524]	75	378.
78	Seasonal_naïve	2024 Q4	N(397, 22560)	397	[351, 443]	50	[318, 476]	75	351.
79	Seasonal_naïve	2025 Q1	N(355, 22560)	355	[309, 401]	50	[276, 434]	75	309.
80	Seasonal_naïve	2025 Q2	N(435, 22560)	435	[389, 481]	50	[356, 514]	75	389.

# Outline

1 Statistical forecasting

2 Benchmark methods

3 Lab Session 11

4 Residual diagnostics

5 Lab Session 12

6 Forecast accuracy measures

7 Lab Session 13

# Lab Session 11

- Produce forecasts using an appropriate benchmark method for household wealth (`hh_budget`). Plot the results using `autoplot()`.
- Produce forecasts using an appropriate benchmark method for Australian takeaway food turnover (`aus_retail`). Plot the results using `autoplot()`.

# Outline

1 Statistical forecasting

2 Benchmark methods

3 Lab Session 11

4 Residual diagnostics

5 Lab Session 12

6 Forecast accuracy measures

7 Lab Session 13

# Fitted values

- $\hat{y}_{t|t-1}$  is the forecast of  $y_t$  based on observations  $y_1, \dots, y_{t-1}$ .
- We call these “fitted values”.
- Sometimes drop the subscript:  $\hat{y}_t \equiv \hat{y}_{t|t-1}$ .
- Often not true forecasts since parameters are estimated on all data.

## For example:

- $\hat{y}_t = \bar{y}$  for average method.
- $\hat{y}_t = y_{t-1} + (y_T - y_1)/(T - 1)$  for drift method.

# Forecasting residuals

**Residuals in forecasting:** difference between observed value and its fitted value:  $e_t = y_t - \hat{y}_{t|t-1}$ .

# Forecasting residuals

**Residuals in forecasting:** difference between observed value and its fitted value:  $e_t = y_t - \hat{y}_{t|t-1}$ .

## Assumptions

- 1  $\{e_t\}$  uncorrelated. If they aren't, then information left in residuals that should be used in computing forecasts.
- 2  $\{e_t\}$  have mean zero. If they don't, then forecasts are biased.

# Forecasting residuals

**Residuals in forecasting:** difference between observed value and its fitted value:  $e_t = y_t - \hat{y}_{t|t-1}$ .

## Assumptions

- 1  $\{e_t\}$  uncorrelated. If they aren't, then information left in residuals that should be used in computing forecasts.
- 2  $\{e_t\}$  have mean zero. If they don't, then forecasts are biased.

## Useful properties (for prediction intervals)

- 3  $\{e_t\}$  have constant variance.
- 4  $\{e_t\}$  are normally distributed.

# Facebook closing stock price

```
fb_stock <- gafa_stock |>  
  filter(Symbol == "FB")  
fb_stock |> autoplot(Close)
```



# Facebook closing stock price

```
fb_stock <- fb_stock |>  
  mutate(trading_day = row_number()) |>  
  update_tsibble(index = trading_day, regular = TRUE)  
fit <- fb_stock |> model(NAIVE(Close))  
augment(fit)
```

```
# A tsibble: 1,258 x 7 [1]  
# Key:     Symbol, .model [1]  
  Symbol .model      trading_day Close .fitted .resid .innov  
  <chr>  <chr>        <int>  <dbl>   <dbl>   <dbl>   <dbl>  
1 FB     NAIVE(Close)      1  54.7    NA    NA    NA  
2 FB     NAIVE(Close)      2  54.6  54.7 -0.150 -0.150  
3 FB     NAIVE(Close)      3  57.2  54.6  2.64  2.64  
4 FB     NAIVE(Close)      4  57.9  57.2  0.720 0.720  
5 FB     NAIVE(Close)      5  58.2  57.9  0.310 0.310  
6 FB     NAIVE(Close)      6  57.2  58.2 -1.01 -1.01  
7 FB     NAIVE(Close)      7  57.9  57.2  0.720 0.720  
8 FB     NAIVE(Close)      8  55.9  57.9 -2.03 -2.03  
9 FB     NAIVE(Close)      9  57.7  55.9  1.83  1.83
```

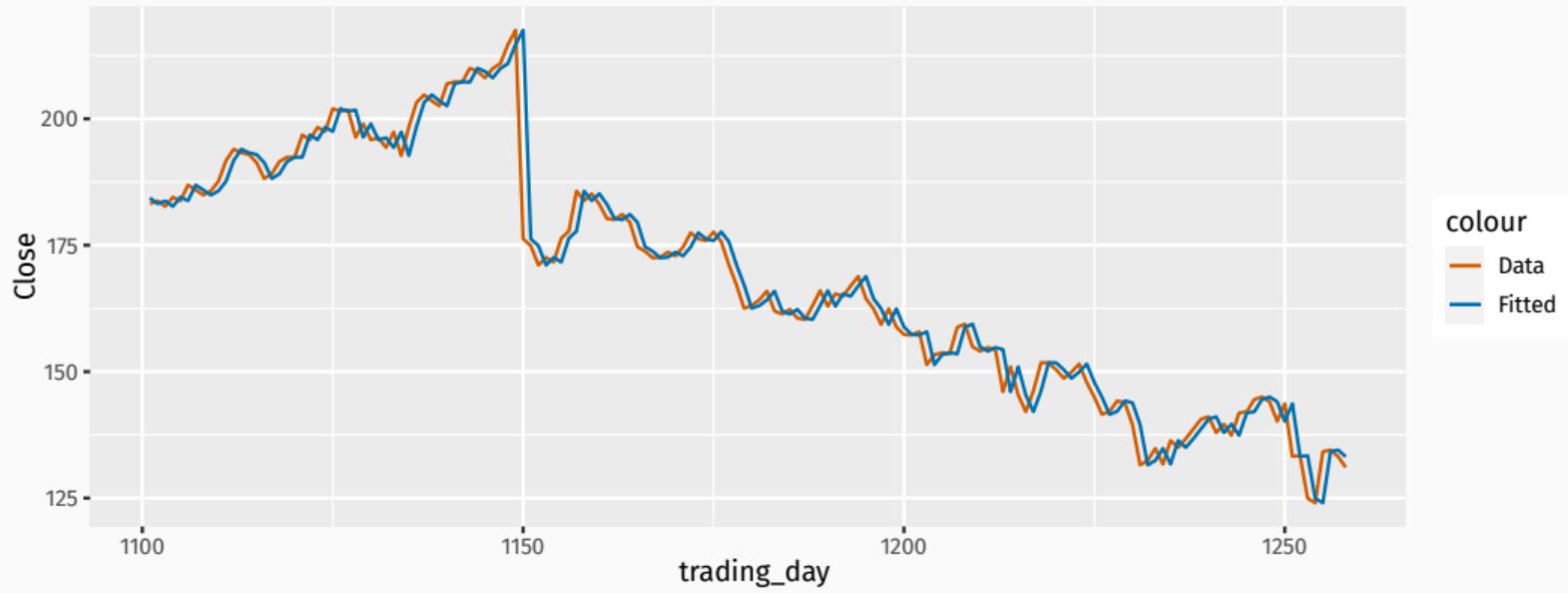
# Facebook closing stock price

```
augment(fit) |>  
  ggplot(aes(x = trading_day)) +  
  geom_line(aes(y = Close, colour = "Data")) +  
  geom_line(aes(y = .fitted, colour = "Fitted"))
```



# Facebook closing stock price

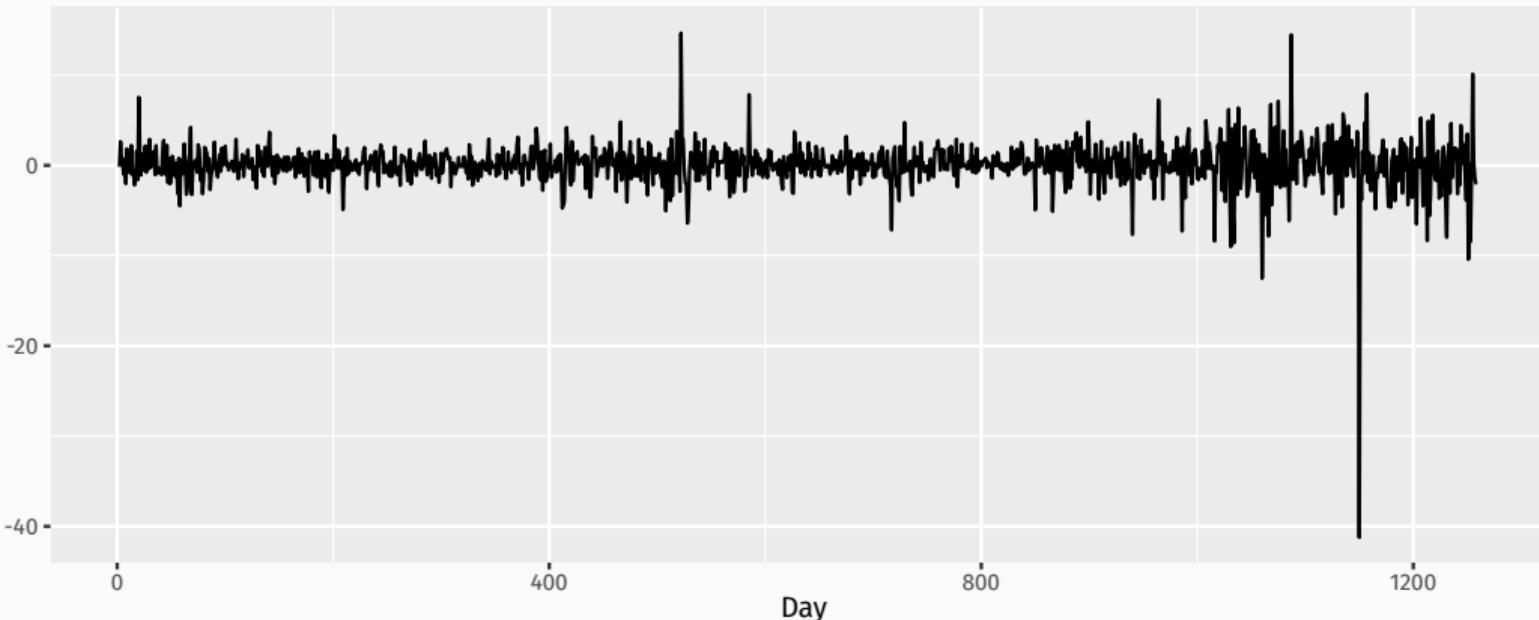
```
augment(fit) |>  
  filter(trading_day > 1100) |>  
  ggplot(aes(x = trading_day)) +  
  geom_line(aes(y = Close, colour = "Data")) +  
  geom_line(aes(y = .fitted, colour = "Fitted"))
```



# Facebook closing stock price

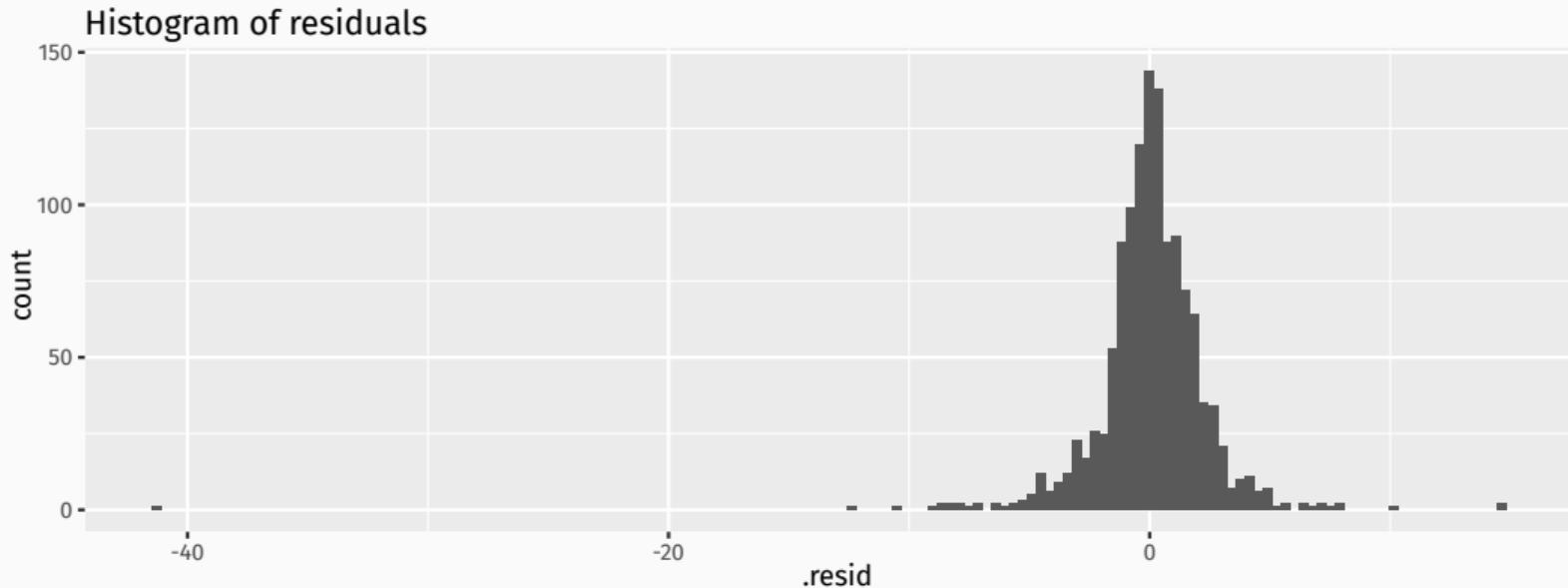
```
augment(fit) |>  
  autoplot(.resid) +  
  labs(x = "Day", y = "", title = "Residuals from naïve method")
```

Residuals from naïve method



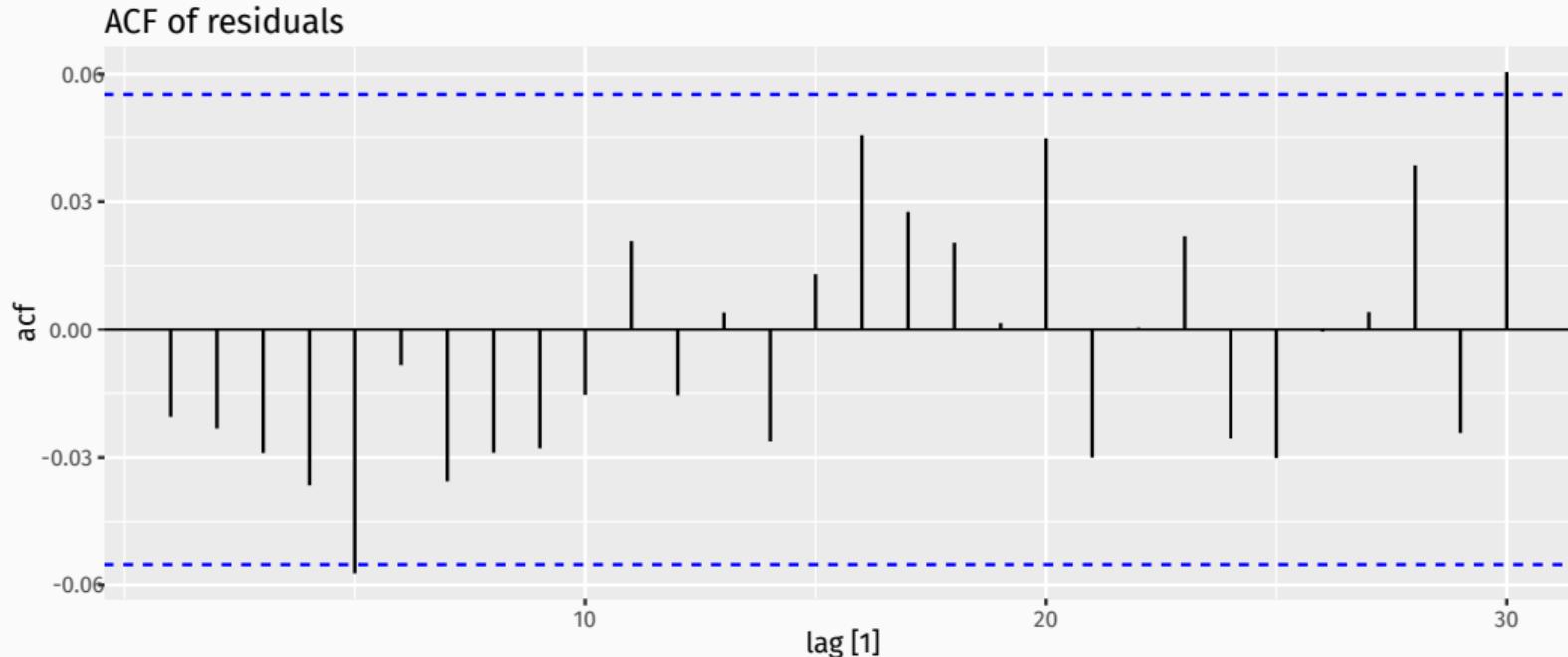
# Facebook closing stock price

```
augment(fit) |>  
  ggplot(aes(x = .resid)) +  
  geom_histogram(bins = 150) +  
  labs(title = "Histogram of residuals")
```



# Facebook closing stock price

```
augment(fit) |>  
ACF(.resid) |>  
autoplot() + labs(title = "ACF of residuals")
```

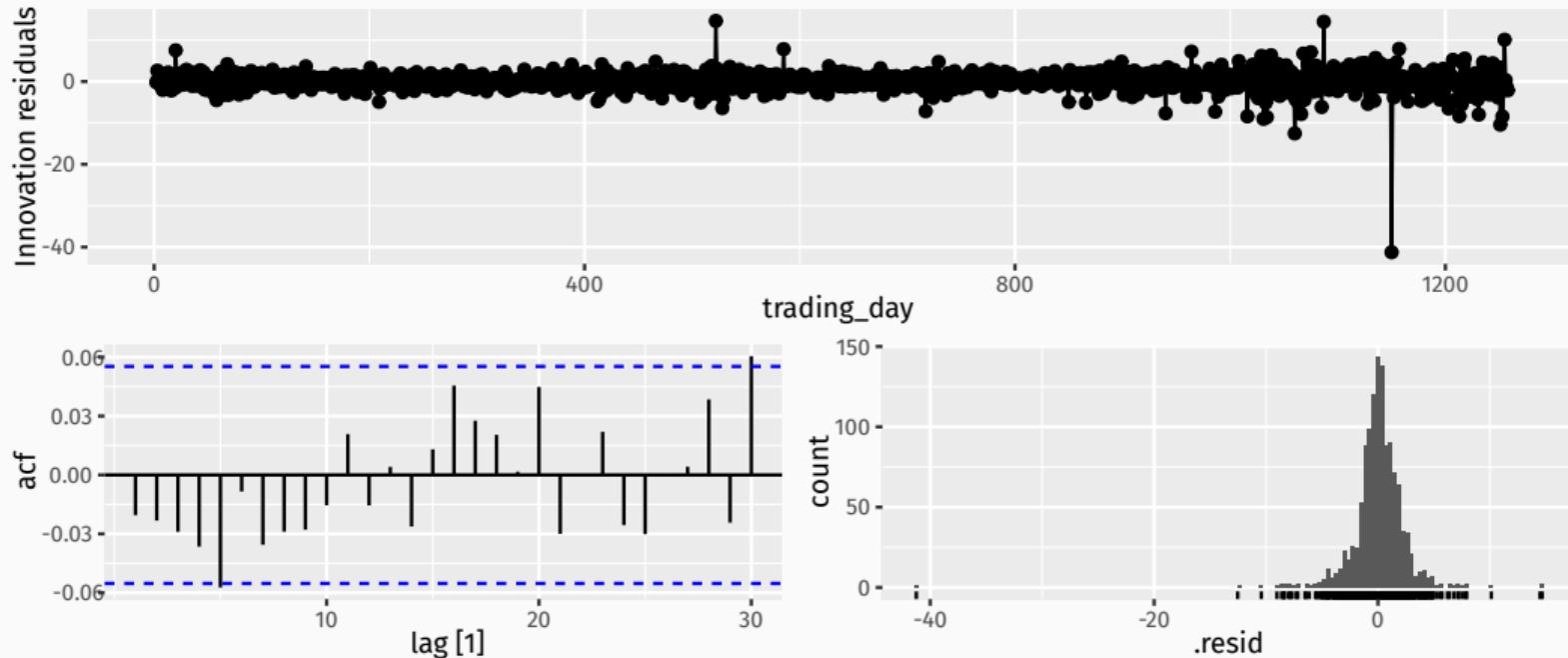


# ACF of residuals

- We assume that the residuals are white noise (uncorrelated, mean zero, constant variance). If they aren't, then there is information left in the residuals that should be used in computing forecasts.
- So a standard residual diagnostic is to check the ACF of the residuals of a forecasting method.
- We *expect* these to look like white noise.

# Combined diagnostic graph

```
fit |> gg_tsresiduals()
```



# Ljung-Box test

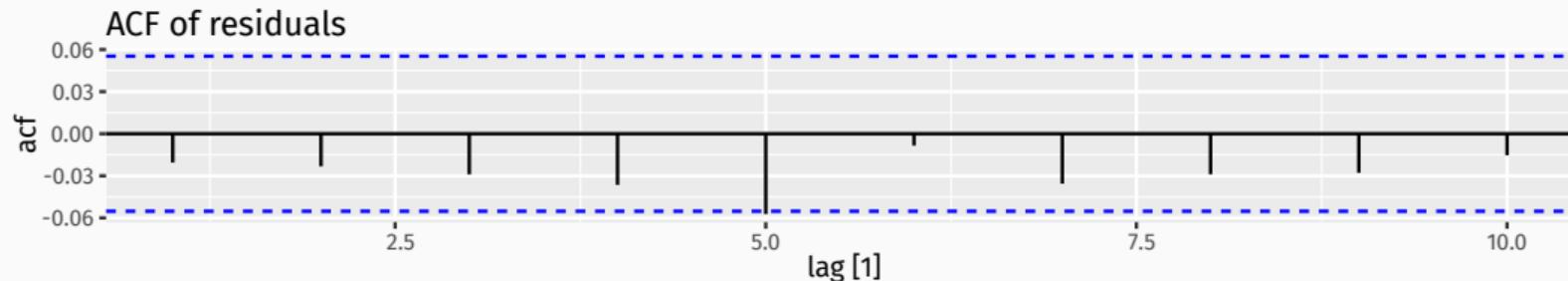
Test whether *whole set* of  $r_k$  values is significantly different from zero set.

$$Q = T(T + 2) \sum_{k=1}^{\ell} (T - k)^{-1} r_k^2 \quad \text{where } \ell = \text{max lag and } T = \# \text{ observations}$$

- If each  $r_k$  close to zero,  $Q$  will be **small**.
- If some  $r_k$  values large (+ or -),  $Q$  will be **large**.
- My preferences:  $h = 10$  for non-seasonal data,  $h = 2m$  for seasonal data.
- If data are WN and  $T$  large,  $Q \sim \chi^2$  with  $\ell$  degrees of freedom.

# Ljung-Box test

$$Q = T(T + 2) \sum_{k=1}^{\ell} (T - k)^{-1} r_k^2 \quad \text{where } \ell = \text{max lag and } T = \# \text{ observations.}$$



```
# lag = h
augment(fit) |> features(.resid, ljung_box, lag = 10)
```

```
# A tibble: 1 x 4
  Symbol .model      lb_stat lb_pvalue
  <chr>  <chr>       <dbl>     <dbl>
1 FB    NAIVE(Close) 12.1      0.276
```

# Outline

1 Statistical forecasting

2 Benchmark methods

3 Lab Session 11

4 Residual diagnostics

5 Lab Session 12

6 Forecast accuracy measures

7 Lab Session 13

## Lab Session 12

- Compute seasonal naïve forecasts for quarterly Australian beer production.
- Test if the residuals are white noise. What do you conclude?

# Outline

- 1 Statistical forecasting
- 2 Benchmark methods
- 3 Lab Session 11
- 4 Residual diagnostics
- 5 Lab Session 12
- 6 Forecast accuracy measures
- 7 Lab Session 13

# Training and test sets



- A model which fits the training data well will not necessarily forecast well.
- Forecast accuracy is based only on the test set.

## Forecast errors

Forecast “error”: the difference between an observed value and its forecast.

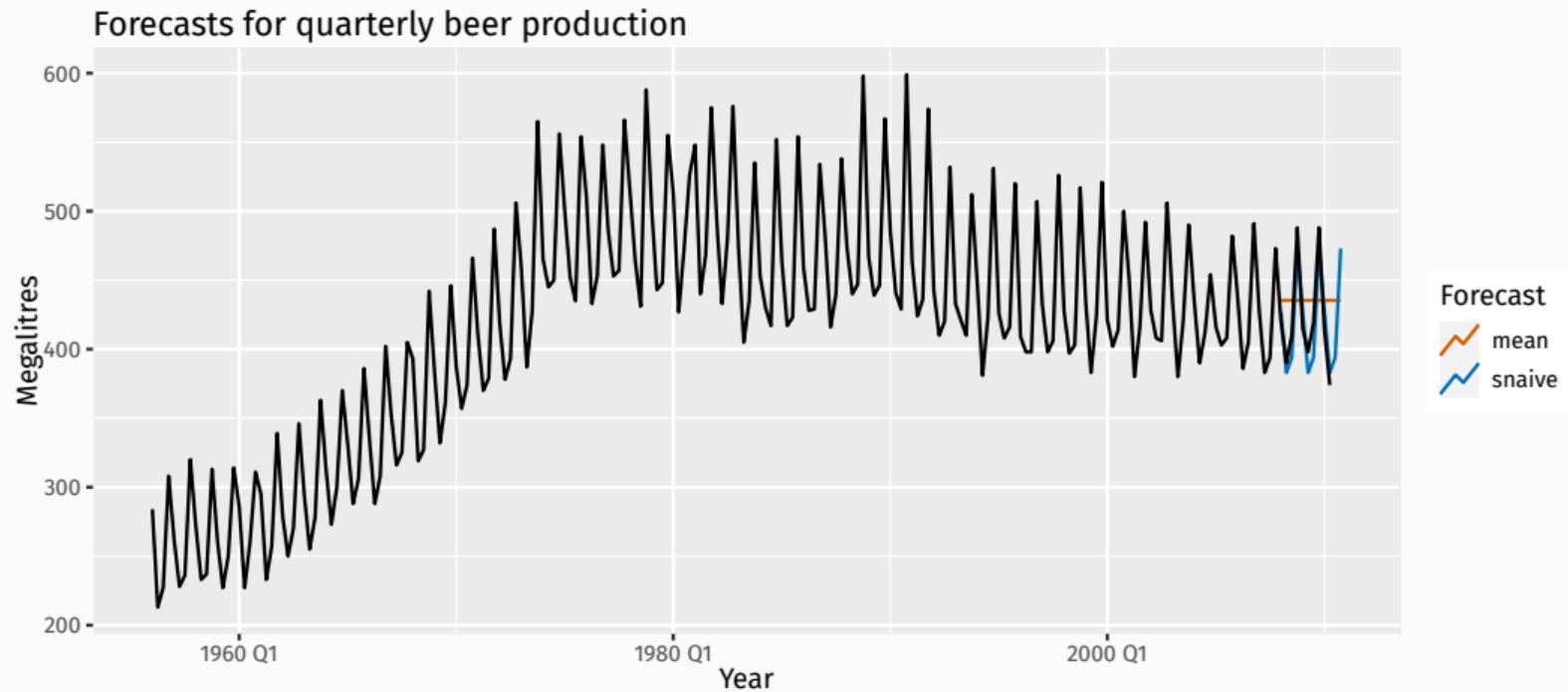
$$e_{T+h} = y_{T+h} - \hat{y}_{T+h|T},$$

where the training data is given by  $\{y_1, \dots, y_T\}$

# Measures of forecast accuracy

```
beer_fit <- aus_production |>
  filter(between(year(Quarter), 1992, 2007)) |>
  model(
    snaive = SNAIVE(Beer),
    mean = MEAN(Beer)
  )
beer_fit |>
  forecast(h = "3 years") |>
  autoplot(aus_production, level = NULL) +
  labs(title ="Forecasts for quarterly beer production",
       x ="Year", y ="Megalitres") +
  guides(colour = guide_legend(title = "Forecast"))
```

# Measures of forecast accuracy



# Measures of forecast accuracy

$y_{T+h}$  =  $(T + h)$ th observation,  $h = 1, \dots, H$

$\hat{y}_{T+h|T}$  = its forecast based on data up to time  $T$ .

$e_{T+h} = y_{T+h} - \hat{y}_{T+h|T}$

MAE =  $\text{mean}(|e_{T+h}|)$

MSE =  $\text{mean}(e_{T+h}^2)$

RMSE =  $\sqrt{\text{mean}(e_{T+h}^2)}$

MAPE =  $100\text{mean}(|e_{T+h}|/|y_{T+h}|)$

# Measures of forecast accuracy

$y_{T+h}$  =  $(T + h)$ th observation,  $h = 1, \dots, H$

$\hat{y}_{T+h|T}$  = its forecast based on data up to time  $T$ .

$e_{T+h} = y_{T+h} - \hat{y}_{T+h|T}$

MAE =  $\text{mean}(|e_{T+h}|)$

MSE =  $\text{mean}(e_{T+h}^2)$

RMSE =  $\sqrt{\text{mean}(e_{T+h}^2)}$

MAPE =  $100\text{mean}(|e_{T+h}|/|y_{T+h}|)$

- MAE, MSE, RMSE are all scale dependent.
- MAPE is scale independent but is only sensible if  $y_t \gg 0$  for all  $t$ , and  $y$  has a natural zero.

# Measures of forecast accuracy

## Mean Absolute Scaled Error

$$\text{MASE} = \text{mean}(|e_{T+h}|/Q)$$

# Measures of forecast accuracy

## Mean Absolute Scaled Error

$$\text{MASE} = \text{mean}(|e_{T+h}| / Q)$$

- For non-seasonal series, scale uses naïve forecasts:

$$Q = \frac{1}{T-1} \sum_{t=2}^T |y_t - y_{t-1}|$$

- For seasonal series, scale uses seasonal naïve forecasts:

$$Q = \frac{1}{T-m} \sum_{t=m+1}^T |y_t - y_{t-m}|$$

where  $m$  is the seasonal frequency

# Measures of forecast accuracy

## Mean Absolute Scaled Error

$$\text{MASE} = \text{mean}(|e_{T+h}|/Q)$$

- For non-seasonal series, scale uses naïve forecasts:

$$Q = \frac{1}{T-1} \sum_{t=2}^T |y_t - y_{t-1}|$$

- For seasonal series, scale uses seasonal naïve forecasts:

$$Q = \frac{1}{T-m} \sum_{t=m+1}^T |y_t - y_{t-m}|$$

where  $m$  is the seasonal frequency

Proposed by Hyndman and Koehler (IJF, 2006).

# Measures of forecast accuracy

## Root Mean Squared Scaled Error

$$\text{RMSSE} = \sqrt{\text{mean}(e_{T+h}^2/Q)}$$

- For non-seasonal series, scale uses naïve forecasts:

$$Q = \frac{1}{T-1} \sum_{t=2}^T (y_t - y_{t-1})^2$$

- For seasonal series, scale uses seasonal naïve forecasts:

$$Q = \frac{1}{T-m} \sum_{t=m+1}^T (y_t - y_{t-m})^2$$

where  $m$  is the seasonal frequency

Proposed by Hyndman and Koehler (IJF, 2006).

# Measures of forecast accuracy

```
beer_fc <- forecast(beer_fit, h = "3 years")
accuracy(beer_fc, aus_production)
```

```
# A tibble: 2 x 10
  .model .type     ME   RMSE    MAE    MPE   MAPE   MASE RMSSE     ACF1
  <chr>  <chr> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
1 mean    Test   -13.8  38.4  34.8 -3.97  8.28  2.20  1.96 -0.0691
2 snaive  Test     5.2  14.3  13.4  1.15  3.17  0.847 0.729  0.132
```

# Outline

1 Statistical forecasting

2 Benchmark methods

3 Lab Session 11

4 Residual diagnostics

5 Lab Session 12

6 Forecast accuracy measures

7 Lab Session 13

# Lab Session 13

- Create a training set for household wealth (`hh_budget`) by withholding the last four years as a test set.
- Fit all the appropriate benchmark methods to the training set and forecast the periods covered by the test set.
- Compute the accuracy of your forecasts. Which method does best?
- Repeat the exercise using the Australian takeaway food turnover data (`aus_retail`) with a test set of four years.