

# Tidy Time Series & Forecasting in R

## 6. Introduction to forecasting

A wide-angle aerial photograph of the San Francisco skyline during sunset. The city's iconic buildings, including the Transamerica Pyramid and the Coit Tower, are silhouetted against a bright orange and yellow sky. The water of the bay is visible in the background.

bit.ly/fable2020



# Outline

- 1 What can we forecast?
- 2 The statistical forecasting perspective
- 3 Benchmark methods
- 4 Lab Session 11
- 5 Residual diagnostics
- 6 Lab Session 12
- 7 Forecast accuracy measures
- 8 Lab Session 13

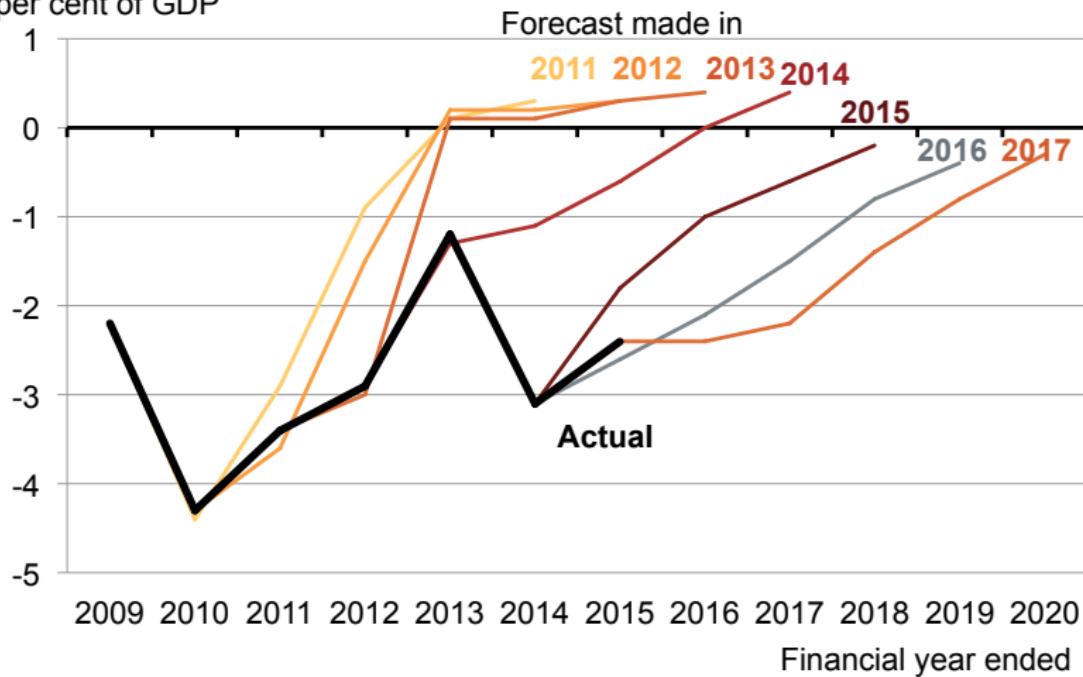
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# Forecasting is difficult

Commonwealth plans to drift back to surplus **GRATTAN Institute**

Actual and forecast Commonwealth underlying cash balance per cent of GDP



## What can we forecast?



# What can we forecast?



# What can we forecast?



# What can we forecast?



# What can we forecast?

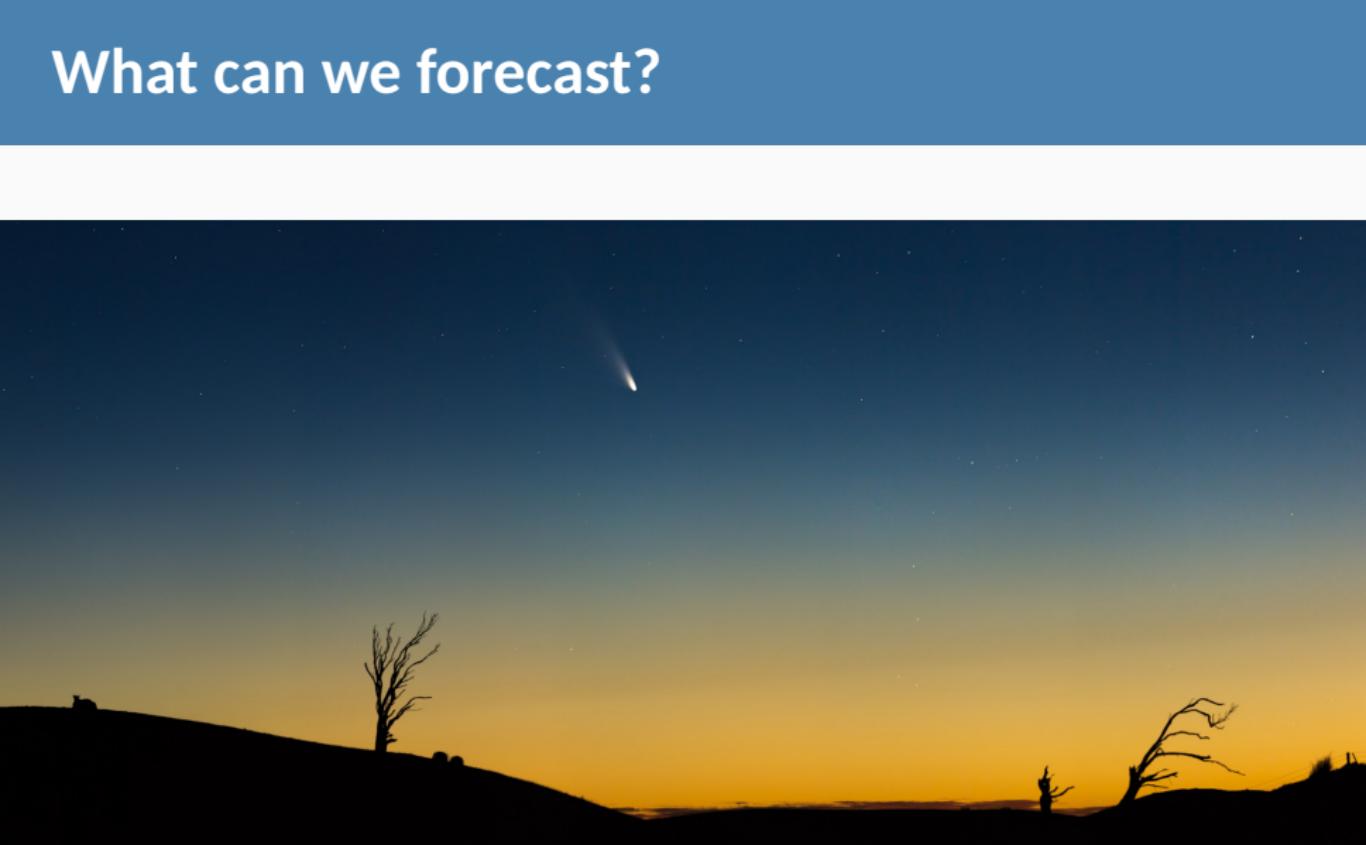
## TOMORROW



# 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

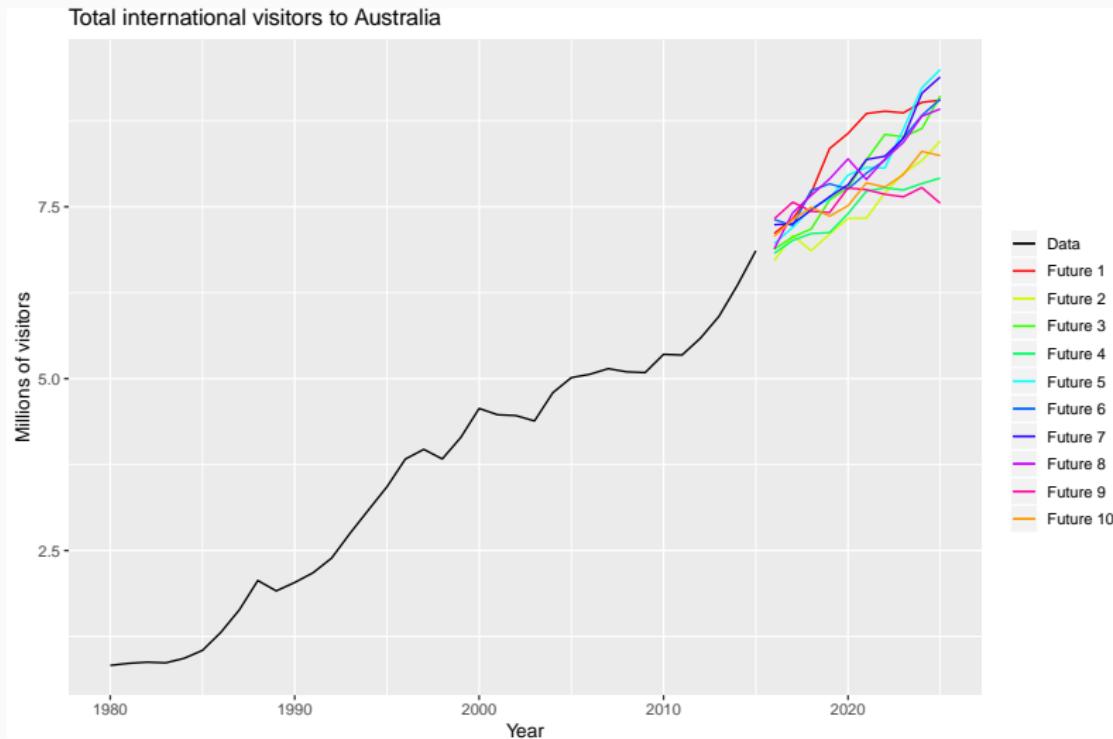
Something is easier to forecast if:

- 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

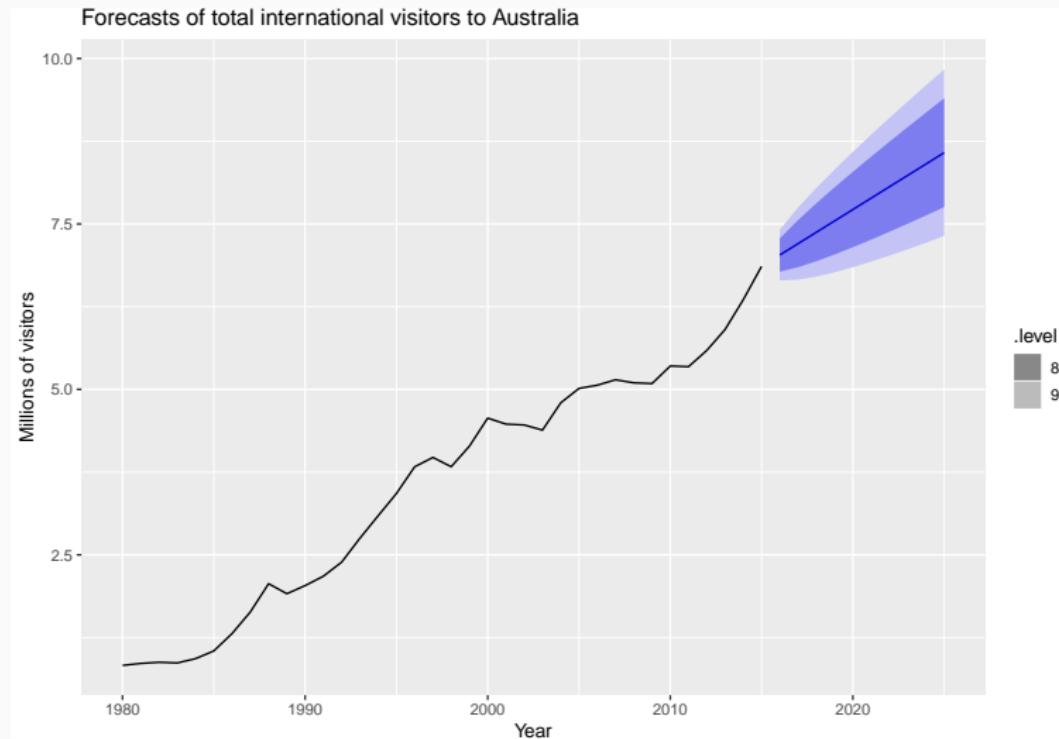
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# Sample futures



# Forecast intervals



# Statistical forecasting

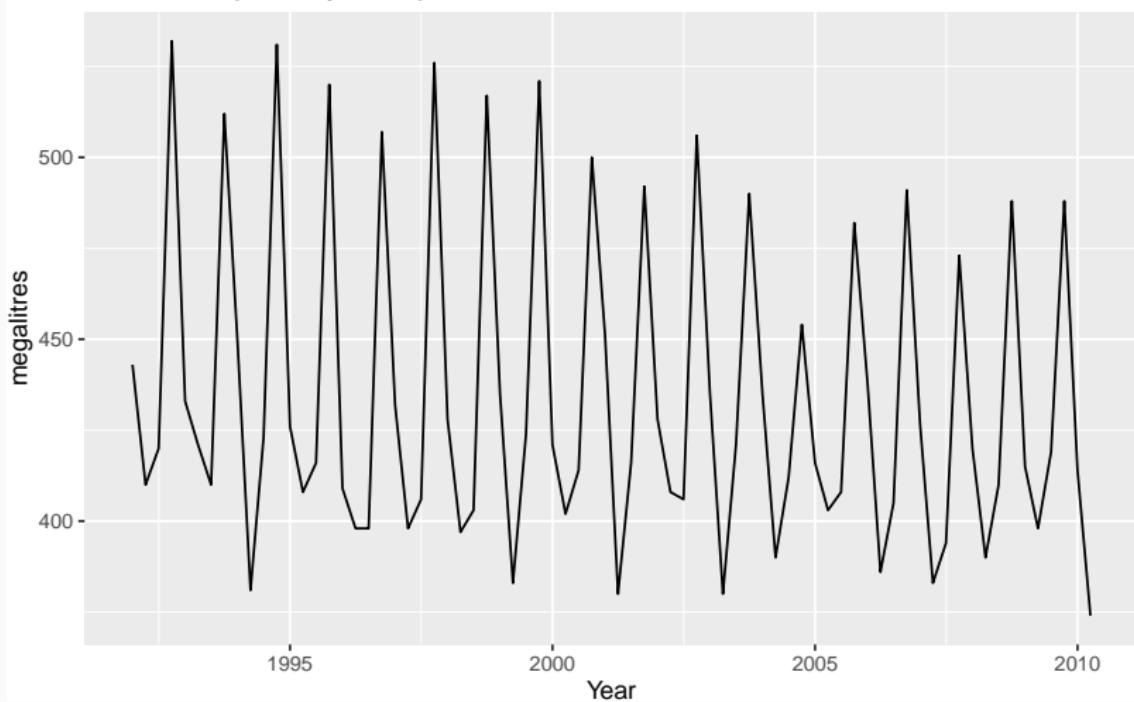
- Thing to be forecast:  $y_{T+h}$ .
- What we know:  $y_1, \dots, y_T$ .
- Forecast distribution:  
 $y_{T+h|t} = y_{T+h} \mid \{y_1, y_2, \dots, y_T\}.$
- Point forecast:  $\hat{y}_{T+h|T} = E[y_{T+h} \mid y_1, \dots, y_T]$ .
- Forecast variance:  $\text{Var}[y_t \mid y_1, \dots, y_T]$
- Prediction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

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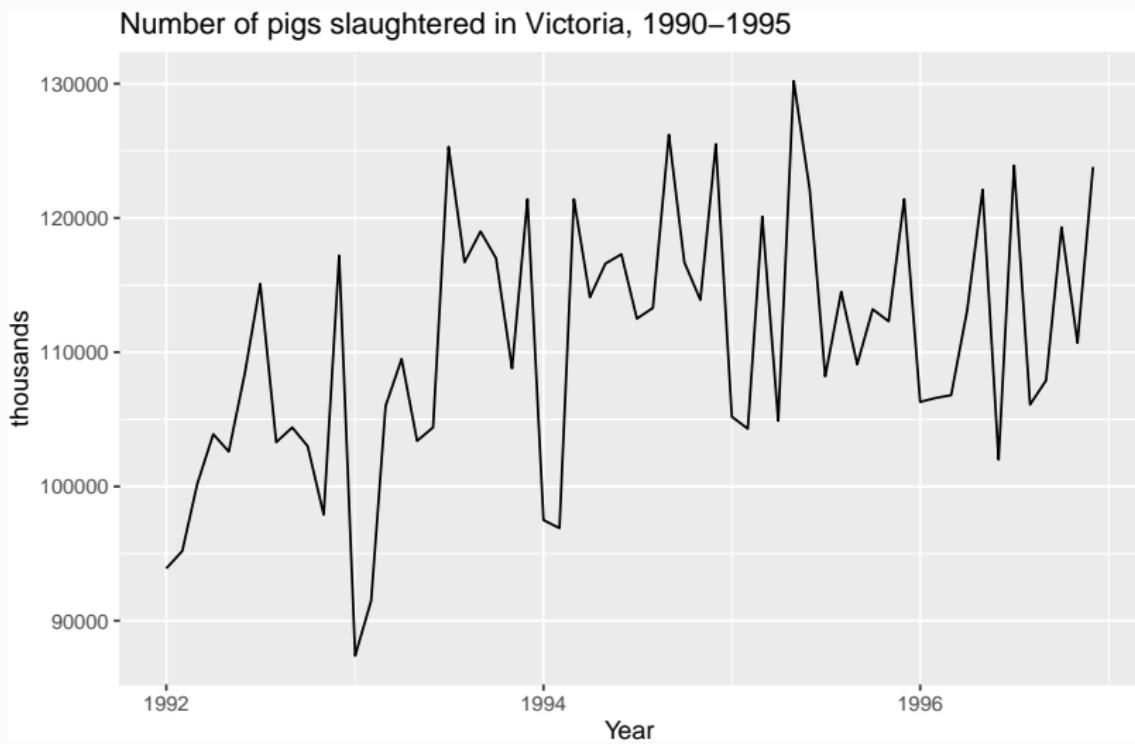
# Some simple forecasting methods

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

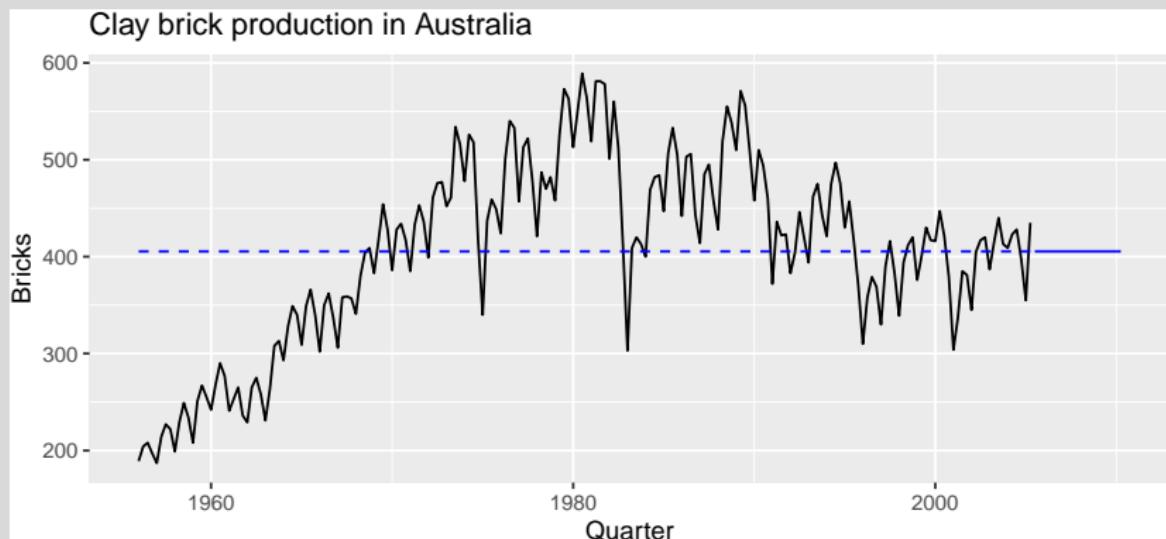


How would you forecast these series?

# 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:  $\hat{y}_{T+h|T} = \bar{y} = (y_1 + \dots + y_T)/T$

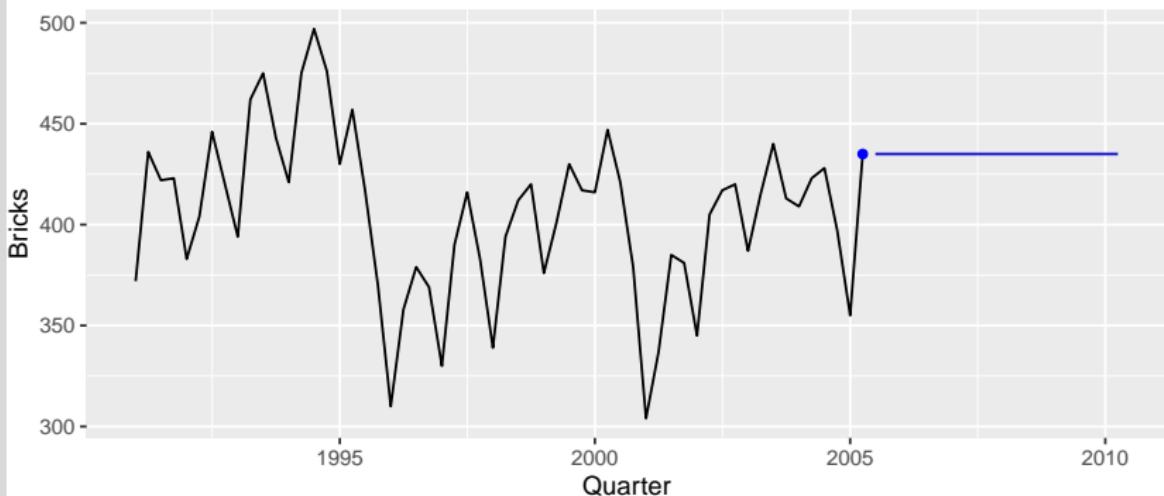


# Some simple forecasting methods

## NAIVE(y): Naïve method

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

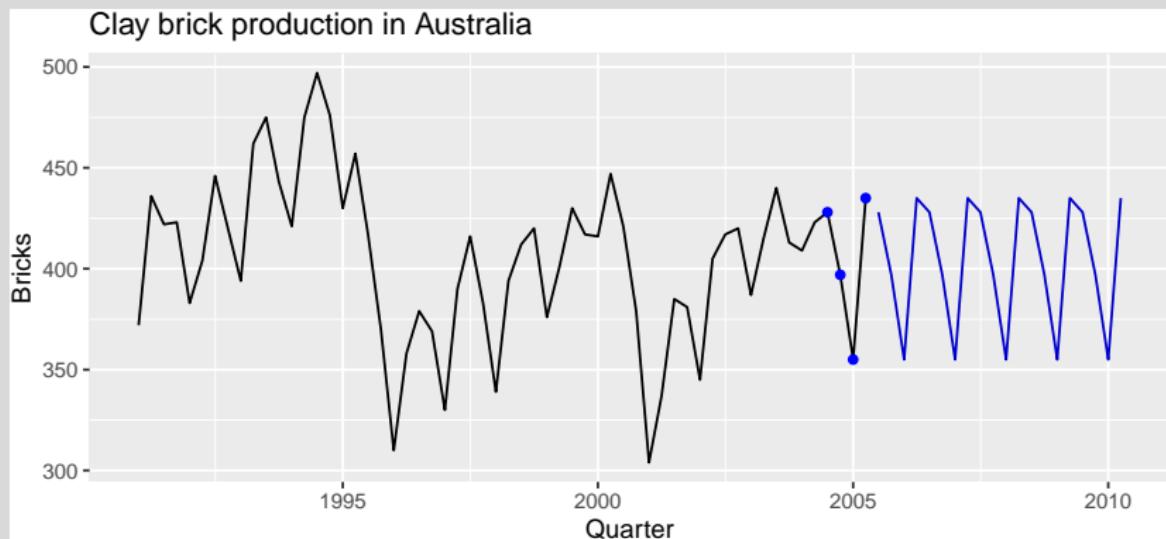
Clay brick production in Australia



# 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

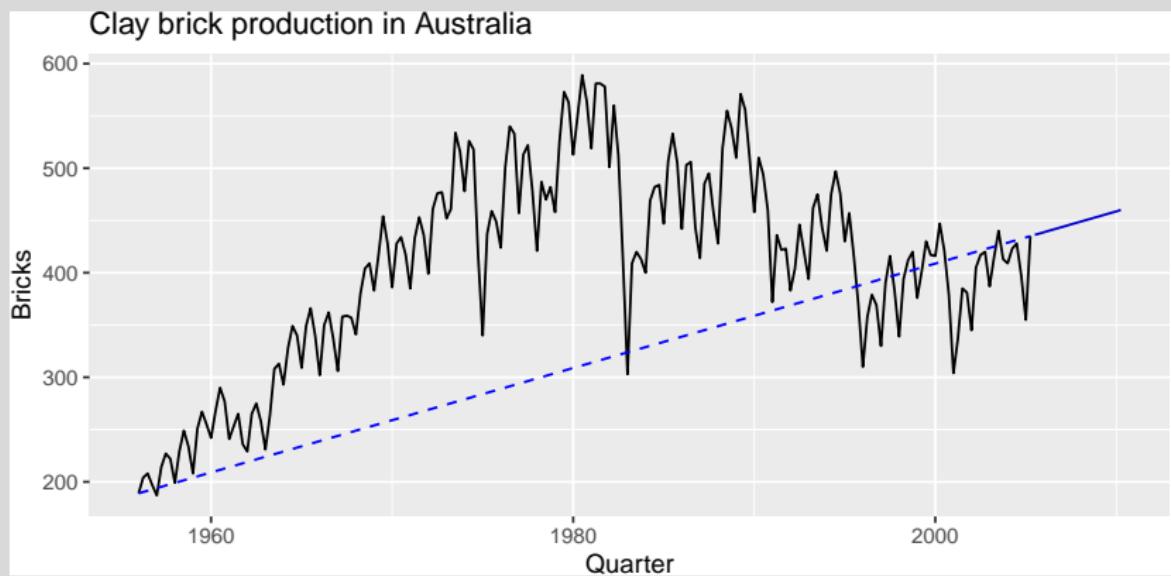
- Forecasts equal to last value plus average change.
- Forecasts:

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

- 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

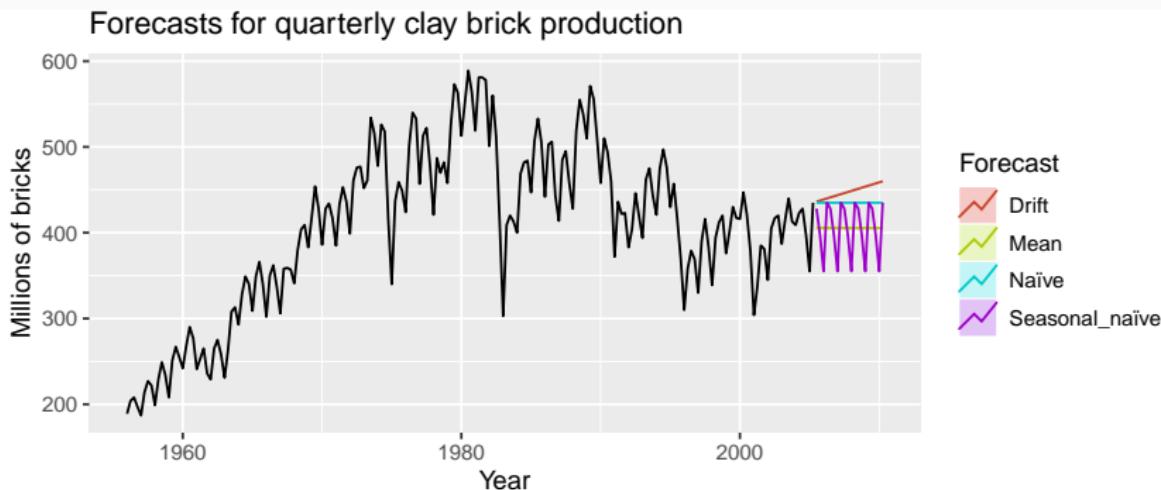
```
brick_fc <- brick_fit %>%  
  forecast(h = "5 years")
```

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

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

# Visualising forecasts

```
brick_fc %>%
  autoplot(aus_production, level = NULL) +
  ggtitle("Forecasts for quarterly clay brick production") +
  xlab("Year") + ylab("Millions of bricks") +
  guides(colour = guide_legend(title = "Forecast"))
```



# Prediction intervals

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

```
## # A tsibble: 80 x 5 [1Q]
## # Key:      .model [4]
##       .model     Quarter Bricks      50%      75%
##       <chr>      <qtr>   <dbl>  <hilo>  <hilo>
## 1 Seasonal_naïve 2005 Q3    428 [395, 461]50 [372, 484]75
## 2 Seasonal_naïve 2005 Q4    397 [364, 430]50 [341, 453]75
## 3 Seasonal_naïve 2006 Q1    355 [322, 388]50 [299, 411]75
## 4 Seasonal_naïve 2006 Q2    435 [402, 468]50 [379, 491]75
## 5 Seasonal_naïve 2006 Q3    428 [382, 474]50 [349, 507]75
## 6 Seasonal_naïve 2006 Q4    397 [351, 443]50 [318, 476]75
## 7 Seasonal_naïve 2007 Q1    355 [309, 401]50 [276, 434]75
## 8 Seasonal_naïve 2007 Q2    435 [389, 481]50 [356, 514]75
## 9 Seasonal_naïve 2007 Q3    428 [372, 484]50 [332, 524]75
## 10 Seasonal_naïve 2007 Q4   397 [341, 453]50 [301, 493]75
```

# Prediction intervals

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

```
## # A tibble: 80 x 9
##   .model   Quarter Bricks .lower .upper .level .lower1 .upper1
##   <chr>     <qtr>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>
## 1 Seaso~ 2005 Q3     428    395.    461.    50     372.    484.
## 2 Seaso~ 2005 Q4     397    364.    430.    50     341.    453.
## 3 Seaso~ 2006 Q1     355    322.    388.    50     299.    411.
## 4 Seaso~ 2006 Q2     435    402.    468.    50     379.    491.
## 5 Seaso~ 2006 Q3     428    382.    474.    50     349.    507.
## 6 Seaso~ 2006 Q4     397    351.    443.    50     318.    476.
## 7 Seaso~ 2007 Q1     355    309.    401.    50     276.    434.
## 8 Seaso~ 2007 Q2     435    389.    481.    50     356.    514.
## 9 Seaso~ 2007 Q3     428    372.    484.    50     332.    524.
## 10 Seaso~ 2007 Q4    397    341.    453.    50     301.    493.
## # ... with 70 more rows, and 1 more variable: .level1 <dbl>
```

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# 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()`.

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# 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:  $e_t = y_t - \hat{y}_{t|t-1}$ .

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## 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

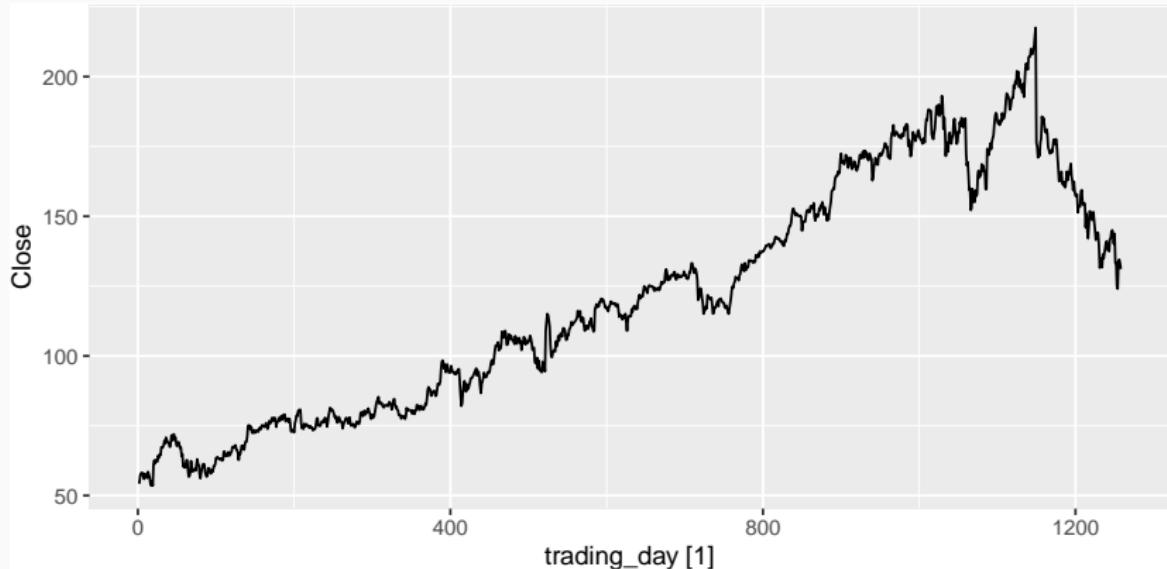
- 1  $\{e_t\}$  uncorrelated. If they aren't, then information left in residuals that should be used in computing forecasts.
- 2  $\{e_t\}$  have mean zero. If they don't, then forecasts are biased.

## 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") %>%  
  mutate(trading_day = row_number()) %>%  
  update_tsibble(index = trading_day, regular = TRUE)  
fb_stock %>% autoplot(Close)
```



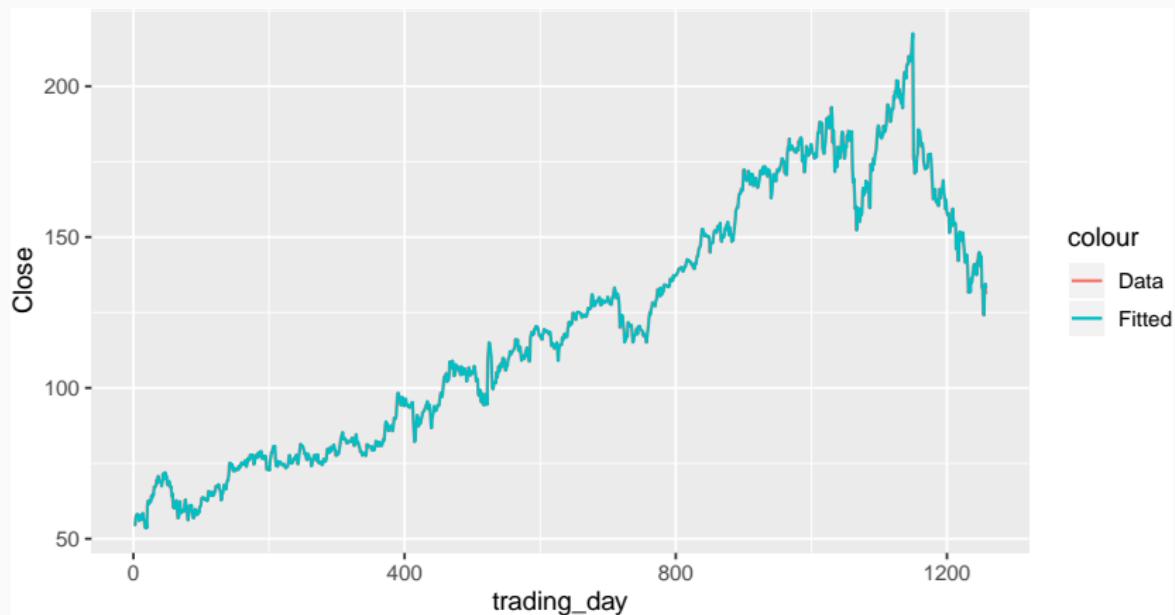
# Facebook closing stock price

```
fit <- fb_stock %>% model(NAIVE(Close))  
augment(fit)
```

```
## # A tsibble: 1,258 x 6 [1]  
## # Key:     Symbol, .model [1]  
##   Symbol .model      trading_day Close .fitted .resid  
##   <chr>  <chr>          <int>  <dbl>    <dbl>    <dbl>  
## 1 FB    NAIVE(Close)        1  54.7     NA     NA  
## 2 FB    NAIVE(Close)        2  54.6  54.7 -0.150  
## 3 FB    NAIVE(Close)        3  57.2  54.6  2.64  
## 4 FB    NAIVE(Close)        4  57.9  57.2  0.720  
## 5 FB    NAIVE(Close)        5  58.2  57.9  0.310  
## 6 FB    NAIVE(Close)        6  57.2  58.2 -1.01  
## 7 FB    NAIVE(Close)        7  57.9  57.2  0.720  
## 8 FB    NAIVE(Close)        8  55.9  57.9 -2.03  
## 9 FB    NAIVE(Close)        9  57.7  55.9  1.83  
## 10 FB   NAIVE(Close)       10  57.6  57.7 -0.140  
## # ... with 1,248 more rows
```

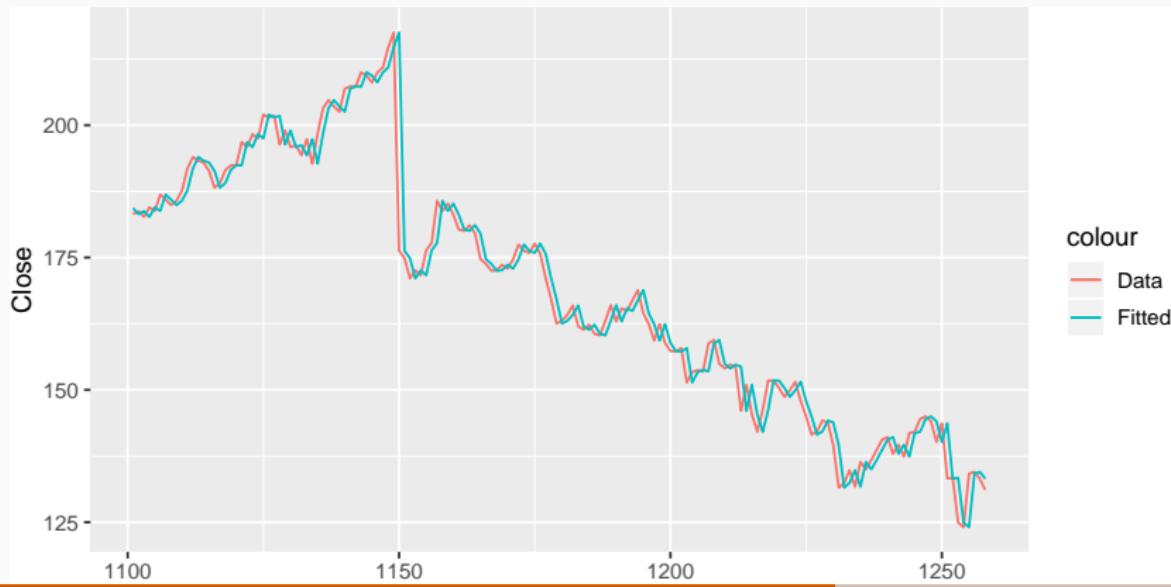
# Facebook closing stock price

```
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

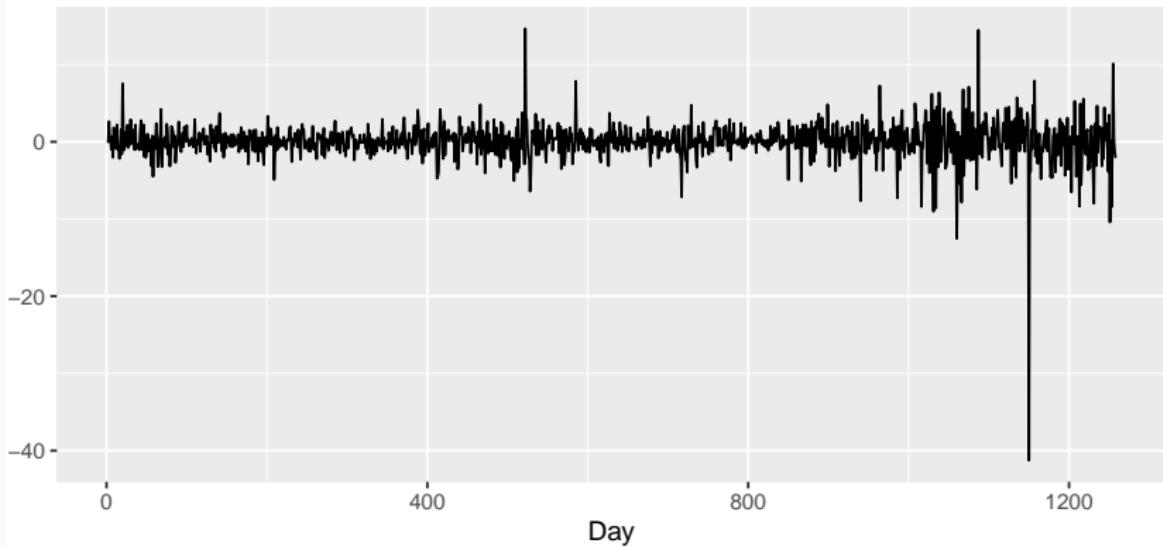
```
augment(fit) %>%
  filter(trading_day > 1100) %>%
  ggplot(aes(x = trading_day)) +
  geom_line(aes(y = Close, colour = "Data")) +
  geom_line(aes(y = .fitted, colour = "Fitted"))
```



# Facebook closing stock price

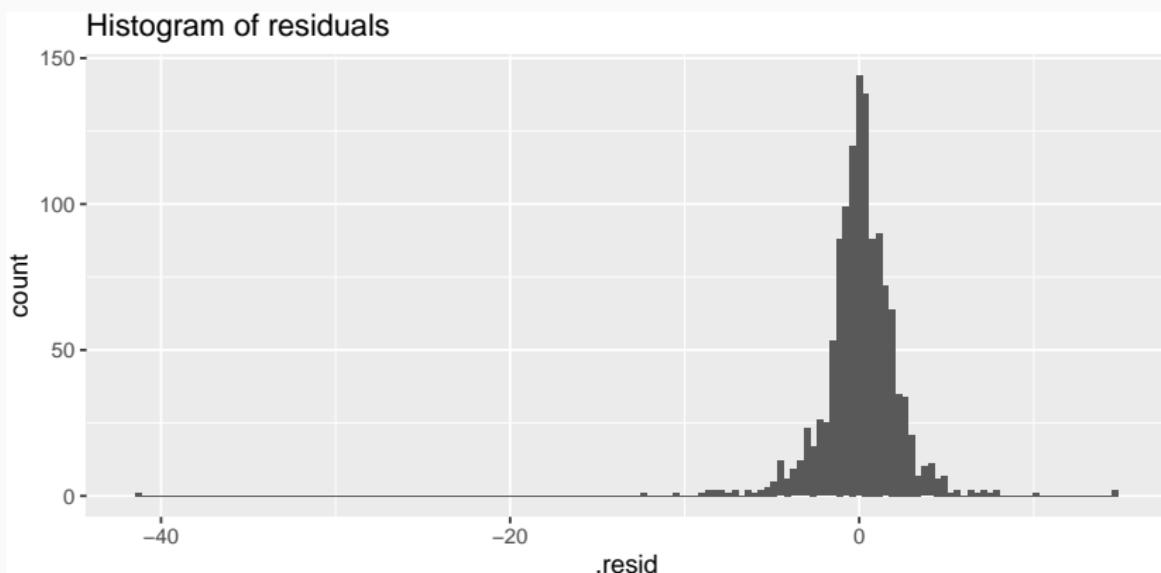
```
augment(fit) %>%
  autoplot(.resid) + xlab("Day") + ylab("") +
  ggtitle("Residuals from naïve method")
```

Residuals from naïve method



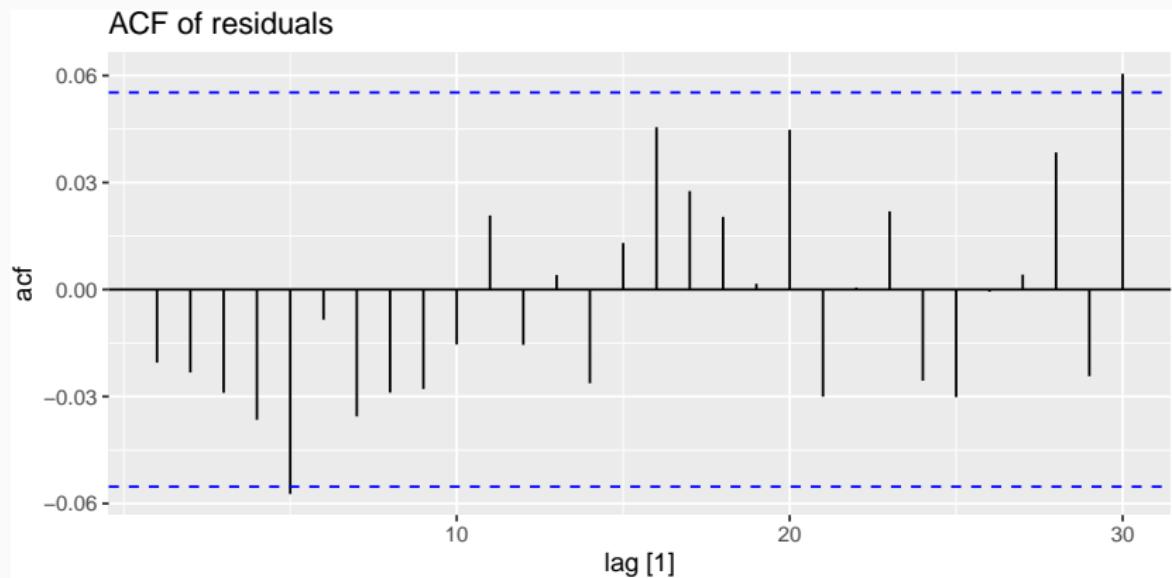
# Facebook closing stock price

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



# Facebook closing stock price

```
augment(fit) %>%
  ACF(.resid) %>%
  autoplot() + ggtitle("ACF of residuals")
```

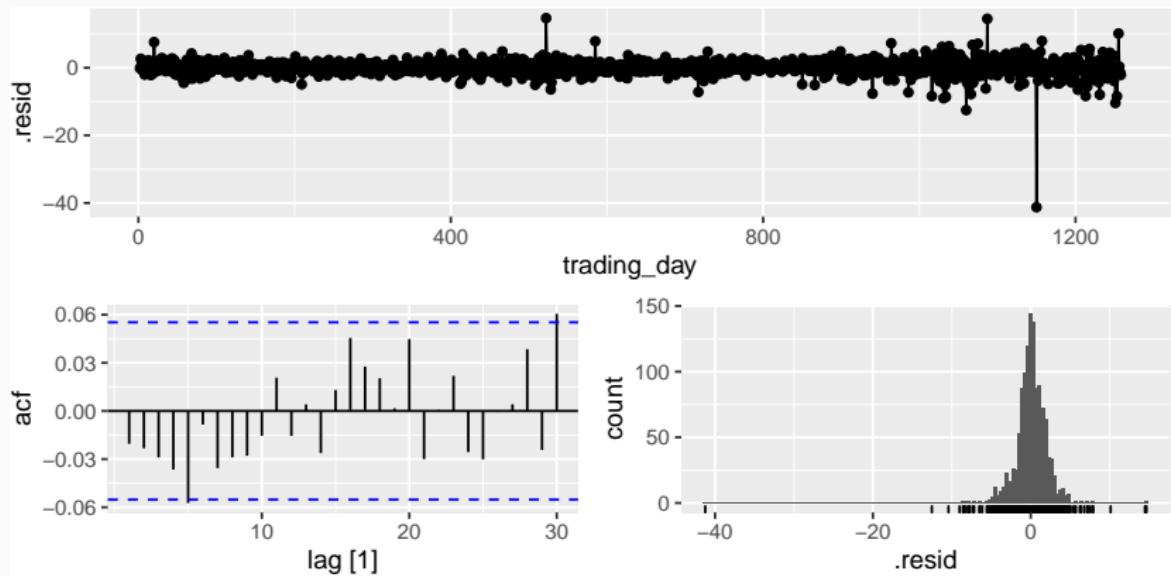


## ACF of residuals

- 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.

$$Q = T(T + 2) \sum_{k=1}^h (T - k)^{-1} r_k^2$$

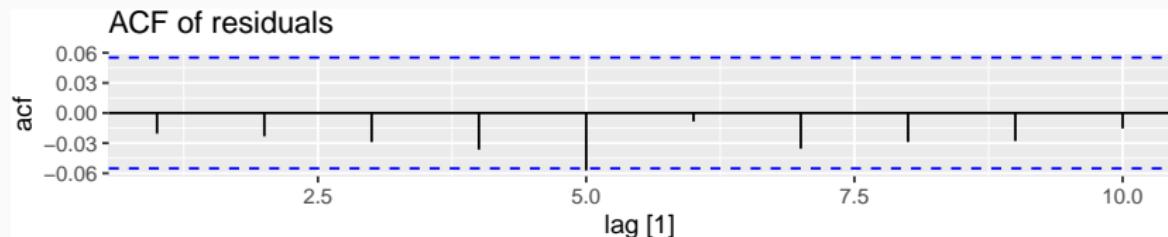
where  $h$  = max lag and  $T$  = # observations.

- 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,  $Q \sim \chi^2$  with  $(h - K)$  degrees of freedom where  $K$  = no. parameters in model.
- When applied to raw data, set  $K = 0$ .

# Ljung-Box test

$$Q = T(T + 2) \sum_{k=1}^h (T - k)^{-1} r_k^2$$

where  $h = \max \text{ lag}$  and  $T = \# \text{ observations}$ .



```
# lag=h and dof=K
augment(fit) %>%
  features(.resid, ljung_box, dof = 0, 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
```

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# Lab Session 12

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

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# 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.

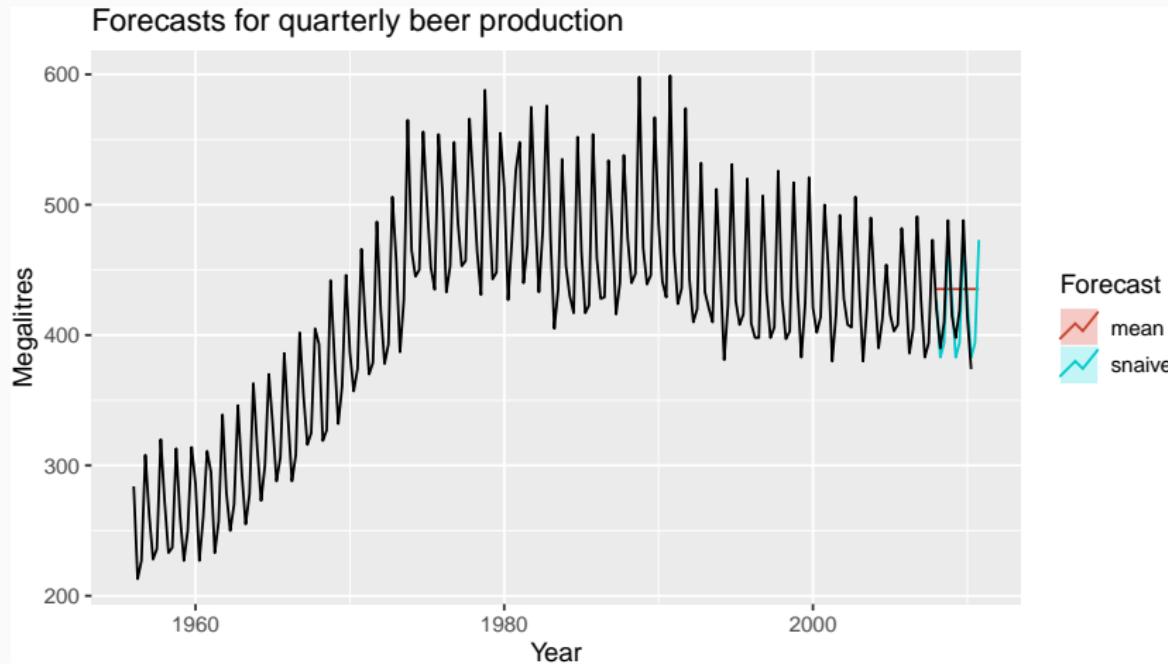
$$e_{T+h} = y_{T+h} - \hat{y}_{T+h|T},$$

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) +  
  ggtitle("Forecasts for quarterly beer production") +  
  xlab("Year") + ylab("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

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

where Q is a stable measure of the scale of the time series  $\{y_t\}$ .

Proposed by Hyndman and Koehler (IJF, 2006).

For non-seasonal time series,

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

works well. Then MASE is equivalent to MAE relative to a naïve method.

# Measures of forecast accuracy

## Mean Absolute Scaled Error

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

where Q is a stable measure of the scale of the time series  $\{y_t\}$ .

Proposed by Hyndman and Koehler (IJF, 2006).

For seasonal time series,

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

works well. Then MASE is equivalent to MAE relative to a seasonal naïve method.

# Measures of forecast accuracy

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

```
## # A tibble: 2 x 9
##   .model .type     ME    RMSE    MAE    MPE    MAPE    MASE    ACF1
##   <chr>  <chr> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
## 1 mean    Test   -13.8  38.4  34.8 -3.97  8.28  2.20 -0.0691
## 2 snaive  Test    5.2  14.3  13.4  1.15  3.17  0.847  0.132
```

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## 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.