https://workshop.f4sg.org/africast/

Africast-Time Series Analysis & Forecasting Using R

1. Basics of time series and data structures

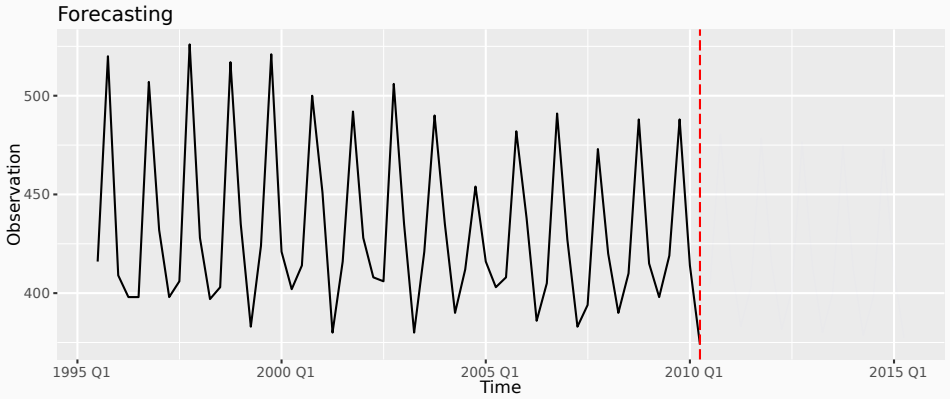
Outline

1. Introduction to forecasting
2. Time series data and tsibbles
3. Example: Australian prison population
4. Example: Australian pharmaceutical sales

Outline

What is a forecast?

Forecasting is estimating how the sequence of observations will continue into the future based on all of the information available at the time when we generate the forecast.



What data do we need for forecasting?

Forecasting is estimating how the sequence of observations will continue into the future based on all of the information available at the time when we generate the forecast:

1. Past/historical time series data on the variable we intend to forecast
2. Past and future data about deterministic predictors/regressors
3. Past and future data about stochastic predictors/regressors
4. Expertise of individuals in an organization and any contextual information that may affect the forecast variable
    - New information

Why does an organisation need forecast?

Why do you use forecast?

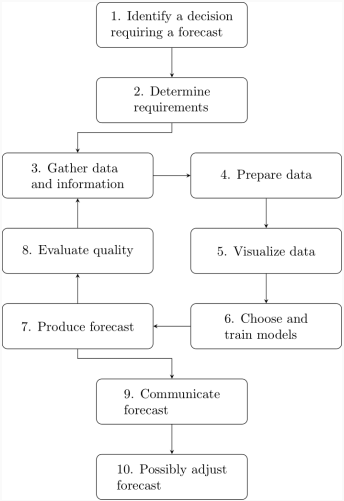
Why does an organisation need forecast?

Why do you use forecast?

Forecasting required in many situation	Forecast
Whether to build a new hospital in next 10 years?	?
How many staff does a call center need next week?	?
How many dose of vaccine is required next month?	?

- An important aid to planning and decision making
  - To inform decisions
  - To provide evidences

Forecasting workflow



Outline

Tidyverts packages

tidyverts.org

Time series data

- Four-yearly Olympic winning times
- Annual Google profits
- Quarterly Australian beer production
- Monthly rainfall
- Weekly retail sales
- Daily IBM stock prices
- Hourly electricity demand
- 5-minute freeway traffic counts
- Time-stamped stock transaction data

Class packages

```
# Data manipulation
library(dplyr)
# Plotting functions
library(ggplot2)
# Time and date manipulation
library(lubridate)
# Time series class
library(tsibble)
# Tidy time series data
library(tsibbledata)
# Time series graphics and statistics
library(feasts)
# Forecasting functions
library(fable)
```

Class packages

```
# Data manipulation
library(dplyr)
# Plotting functions
library(ggplot2)
# Time and date manipulation
library(lubridate)
# Time series class
library(tsibble)
# Tidy time series data
library(tsibbledata)
# Time series graphics and statistics
library(feasts)
# Forecasting functions
library(fable)
```

```
# All of the above
library(fpp3)
```

tsibble objects

```
global_economy
```

```
# A tsibble: 15,150 x 6 [1Y]
# Key:       Country [263]
    Year Country              GDP Imports Exports Population
   <dbl> <fct>              <dbl>   <dbl>   <dbl>      <dbl>
 1  1960 Afghanistan  537777811.    7.02    4.13    8996351
 2  1961 Afghanistan  548888896.    8.10    4.45    9166764
 3  1962 Afghanistan  546666678.    9.35    4.88    9345868
 4  1963 Afghanistan  751111191.   16.9     9.17    9533954
 5  1964 Afghanistan  800000044.   18.1     8.89    9731361
 6  1965 Afghanistan 1006666638.   21.4    11.3     9938414
 7  1966 Afghanistan 1399999967.   18.6     8.57   10152331
 8  1967 Afghanistan 1673333418.   14.2     6.77   10372630
 9  1968 Afghanistan 1373333367.   15.2     8.90   10604346
10  1969 Afghanistan 1408888922.   15.0    10.1    10854428
```

`tsibble` objects

```
global_economy
```

```
# A tsibble: 15,150 x 6 [1Y]
# Key:       Country [263]
```

Index

	Year	Country	GDP	Imports	Exports	Population
	<dbl>	<fct>	<dbl>	<dbl>	<dbl>	<dbl>
1	1960	Afghanistan	537777811.	7.02	4.13	8996351
2	1961	Afghanistan	548888896.	8.10	4.45	9166764
3	1962	Afghanistan	546666678.	9.35	4.88	9345868
4	1963	Afghanistan	751111191.	16.9	9.17	9533954
5	1964	Afghanistan	800000044.	18.1	8.89	9731361
6	1965	Afghanistan	1006666638.	21.4	11.3	9938414
7	1966	Afghanistan	1399999967.	18.6	8.57	10152331
8	1967	Afghanistan	1673333418.	14.2	6.77	10372630
9	1968	Afghanistan	1373333367.	15.2	8.90	10604346
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tsibble objects

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```

Index Key

	Year	Country	GDP	Imports	Exports	Population
	<dbl>	<fct>	<dbl>	<dbl>	<dbl>	<dbl>
1	1960	Afghanistan	537777811.	7.02	4.13	8996351
2	1961	Afghanistan	548888896.	8.10	4.45	9166764
3	1962	Afghanistan	546666678.	9.35	4.88	9345868
4	1963	Afghanistan	751111191.	16.9	9.17	9533954
5	1964	Afghanistan	800000044.	18.1	8.89	9731361
6	1965	Afghanistan	1006666638.	21.4	11.3	9938414
7	1966	Afghanistan	1399999967.	18.6	8.57	10152331
8	1967	Afghanistan	1673333418.	14.2	6.77	10372630
9	1968	Afghanistan	1373333367.	15.2	8.90	10604346
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`tsibble` objects

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global_economy
```

```
# A tsibble: 15,150 x 6 [1Y]
# Key:       Country [263]
```

Index Key Measured variables

```
   Year <fct>          <dbl>  <dbl>  <dbl>      <dbl>
 1  1960 Afghanistan  537777811.    7.02    4.13    8996351
 2  1961 Afghanistan  548888896.    8.10    4.45    9166764
 3  1962 Afghanistan  546666678.    9.35    4.88    9345868
 4  1963 Afghanistan  751111191.   16.9     9.17    9533954
 5  1964 Afghanistan  800000044.   18.1     8.89    9731361
 6  1965 Afghanistan 1006666638.   21.4    11.3     9938414
 7  1966 Afghanistan 1399999967.   18.6     8.57   10152331
 8  1967 Afghanistan 1673333418.   14.2     6.77   10372630
 9  1968 Afghanistan 1373333367.   15.2     8.90   10604346
10  1969 Afghanistan 1408888922.   15.0    10.1    10854428
```

`tsibble` objects

```
tourism
```

```
# A tsibble: 24,320 x 5 [1Q]
# Key:       Region, State, Purpose [304]
   Quarter Region   State Purpose  Trips
     <qtr> <chr>    <chr> <chr>    <dbl>
 1 1998 Q1 Adelaide SA    Business  135.
 2 1998 Q2 Adelaide SA    Business  110.
 3 1998 Q3 Adelaide SA    Business  166.
 4 1998 Q4 Adelaide SA    Business  127.
 5 1999 Q1 Adelaide SA    Business  137.
 6 1999 Q2 Adelaide SA    Business  200.
 7 1999 Q3 Adelaide SA    Business  169.
 8 1999 Q4 Adelaide SA    Business  134.
 9 2000 Q1 Adelaide SA    Business  154.
10 2000 Q2 Adelaide SA    Business  169.
# i 24,310 more rows
```

Domestic visitor nights in thousands by state/region and purpose.

`tsibble` objects

```
tourism
```

```
# A tsibble: 24,320 x 5 [1Q]
# Key:       Region, State, Purpose [304]
    Quarter Region   State Purpose  Trips
      <qtr> <chr>    <chr> <chr>    <dbl>
 1 1998 Q1 Adelaide SA    Business  135.
 2 1998 Q2 Adelaide SA    Business  110.
 3 1998 Q3 Adelaide SA    Business  166.
 4 1998 Q4 Adelaide SA    Business  127.
 5 1999 Q1 Adelaide SA    Business  137.
 6 1999 Q2 Adelaide SA    Business  200.
 7 1999 Q3 Adelaide SA    Business  169.
 8 1999 Q4 Adelaide SA    Business  134.
 9 2000 Q1 Adelaide SA    Business  154.
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# i 24,310 more rows
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Index

Domestic visitor nights in thousands by state/region and purpose.

tsibble objects

```
tourism
```

```
# A tsibble: 24,320 x 5 [1Q]
# Key:       Region, State, Purpose [304]
    Index  Keys                                  Trips
      <qtr> <chr>     <chr> <chr>                <dbl>
 1 1998 Q1 Adelaide SA    Business  135.
 2 1998 Q2 Adelaide SA    Business  110.
 3 1998 Q3 Adelaide SA    Business  166.
 4 1998 Q4 Adelaide SA    Business  127.
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 6 1999 Q2 Adelaide SA    Business  200.
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 8 1999 Q4 Adelaide SA    Business  134.
 9 2000 Q1 Adelaide SA    Business  154.
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# i 24,310 more rows
```

Domestic visitor nights in thousands by state/region and purpose.

`tsibble` objects

```
tourism
```

```
# A tsibble: 24,320 x 5 [1Q]
# Key:       Region, State, Purpose [304]
```

Index | Keys | Measure

```
     <qtr> <chr>     <chr> <chr>      <dbl>
 1 1998 Q1 Adelaide SA    Business   135.
 2 1998 Q2 Adelaide SA    Business   110.
 3 1998 Q3 Adelaide SA    Business   166.
 4 1998 Q4 Adelaide SA    Business   127.
 5 1999 Q1 Adelaide SA    Business   137.
 6 1999 Q2 Adelaide SA    Business   200.
 7 1999 Q3 Adelaide SA    Business   169.
 8 1999 Q4 Adelaide SA    Business   134.
 9 2000 Q1 Adelaide SA    Business   154.
10 2000 Q2 Adelaide SA    Business   169.
# i 24,310 more rows
```

Domestic visitor nights in thousands by state/region and purpose.

`tsibble` objects

- A `tsibble` allows storage and manipulation of multiple time series in R.
- It contains:
  - An index: time information about the observation
  - Measured variable(s): numbers of interest
  - Key variable(s): optional unique identifiers for each series
- It works with tidyverse functions.

The `tsibble` index

Example

```
mydata <- tsibble(
  year = 2012:2016,
  y = c(123, 39, 78, 52, 110),
  index = year
)
mydata
```

```
# A tsibble: 5 x 2 [1Y]
   year     y
  <int> <dbl>
1  2012   123
2  2013    39
3  2014    78
4  2015    52
5  2016   110
```

The `tsibble` index

For observations more frequent than once per year, we need to use a time class function on the index.

```
z
```

```
# A tibble: 5 x 2
  Month    Observation
  <chr>          <dbl>
1 2019 Jan          50
2 2019 Feb          23
3 2019 Mar          34
4 2019 Apr          30
5 2019 May          25
```

The `tsibble` index

For observations more frequent than once per year, we need to use a time class function on the index.

```
z |>
  mutate(Month = yearmonth(Month)) |>
  as_tsibble(index = Month)
```

```
# A tsibble: 5 x 2 [1M]
     Month Observation
     <mth>       <dbl>
1 2019 Jan          50
2 2019 Feb          23
3 2019 Mar          34
4 2019 Apr          30
5 2019 May          25
```

The `tsibble` index

Common time index variables can be created with these functions:

Frequency	Function
Annual	`start:end`
Quarterly	`yearquarter()`
Monthly	`yearmonth()`
Weekly	`yearweek()`
Daily	`as_date()`, `ymd()`
Sub-daily	`as_datetime()`

Outline

Australian prison population

Read a csv file and convert to a tsibble

```
prison <- readr::read_csv("data/prison_population.csv")
```

```
# A tibble: 3,072 x 6
   date       state gender legal     indigenous count
   <date>     <chr> <chr>  <chr>     <chr>      <dbl>
 1 2005-03-01 ACT   Female Remanded  ATSI           0
 2 2005-03-01 ACT   Female Remanded  Other          2
 3 2005-03-01 ACT   Female Sentenced ATSI           0
 4 2005-03-01 ACT   Female Sentenced Other          0
 5 2005-03-01 ACT   Male   Remanded  ATSI           7
 6 2005-03-01 ACT   Male   Remanded  Other         58
 7 2005-03-01 ACT   Male   Sentenced ATSI           0
 8 2005-03-01 ACT   Male   Sentenced Other          0
 9 2005-03-01 NSW   Female Remanded  ATSI          51
10 2005-03-01 NSW   Female Remanded  Other        131
# i 3,062 more rows
```

Read a csv file and convert to a tsibble

```
prison <- readr::read_csv("data/prison_population.csv") |>
  mutate(Quarter = yearquarter(date))
```

```
# A tibble: 3,072 x 7
   date       state gender legal     indigenous count Quarter
   <date>     <chr> <chr>  <chr>     <chr>      <dbl>   <qtr>
 1 2005-03-01 ACT   Female Remanded  ATSI           0 2005 Q1
 2 2005-03-01 ACT   Female Remanded  Other          2 2005 Q1
 3 2005-03-01 ACT   Female Sentenced ATSI           0 2005 Q1
 4 2005-03-01 ACT   Female Sentenced Other          0 2005 Q1
 5 2005-03-01 ACT   Male   Remanded  ATSI           7 2005 Q1
 6 2005-03-01 ACT   Male   Remanded  Other         58 2005 Q1
 7 2005-03-01 ACT   Male   Sentenced ATSI           0 2005 Q1
 8 2005-03-01 ACT   Male   Sentenced Other          0 2005 Q1
 9 2005-03-01 NSW   Female Remanded  ATSI          51 2005 Q1
10 2005-03-01 NSW   Female Remanded  Other        131 2005 Q1
# i 3,062 more rows
```

Read a csv file and convert to a tsibble

```
prison <- readr::read_csv("data/prison_population.csv") |>
  mutate(Quarter = yearquarter(date)) |>
  select(-date)
```

```
# A tibble: 3,072 x 6
   state gender legal     indigenous count Quarter
   <chr> <chr>  <chr>     <chr>      <dbl>   <qtr>
 1 ACT   Female Remanded  ATSI           0 2005 Q1
 2 ACT   Female Remanded  Other          2 2005 Q1
 3 ACT   Female Sentenced ATSI           0 2005 Q1
 4 ACT   Female Sentenced Other          0 2005 Q1
 5 ACT   Male   Remanded  ATSI           7 2005 Q1
 6 ACT   Male   Remanded  Other         58 2005 Q1
 7 ACT   Male   Sentenced ATSI           0 2005 Q1
 8 ACT   Male   Sentenced Other          0 2005 Q1
 9 NSW   Female Remanded  ATSI          51 2005 Q1
10 NSW   Female Remanded  Other        131 2005 Q1
```

Read a csv file and convert to a tsibble

```
prison <- readr::read_csv("data/prison_population.csv") |>
  mutate(Quarter = yearquarter(date)) |>
  select(-date) |>
  as_tsibble(
    index = Quarter,
    key = c(state, gender, legal, indigenous)
  )
```

```
# A tsibble: 3,072 x 6 [1Q]
# Key:       state, gender, legal, indigenous [64]
   state gender legal    indigenous count Quarter
   <chr> <chr>  <chr>    <chr>      <dbl>   <qtr>
 1 ACT   Female Remanded ATSI           0 2005 Q1
 2 ACT   Female Remanded ATSI           1 2005 Q2
 3 ACT   Female Remanded ATSI           0 2005 Q3
 4 ACT   Female Remanded ATSI           0 2005 Q4
 5 ACT   Female Remanded ATSI           1 2006 Q1
```

Outline

Australian Pharmaceutical Benefits Scheme

Australian Pharmaceutical Benefits Scheme

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

Australian Pharmaceutical Benefits Scheme

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.
- Costs are disaggregated by drug type (ATC1 x15 / ATC2 84), concession category (x2) and patient type (x2), giving $84 \times 2 \times 2 = 336$ time series.

Working with `tsibble` objects

PBS

```
# A tsibble: 67,596 x 9 [1M]
# Key:       Concession, Type, ATC1, ATC2 [336]
      Month Concession   Type    ATC1  ATC1_desc ATC2  ATC2_desc Scripts  Cost
      <mth> <chr>        <chr>   <chr> <chr>     <chr> <chr>       <dbl> <dbl>
 1 1991 Jul Concessional Co-pay~ A     Alimenta~ A01   STOMATOL~   18228 67877
 2 1991 Aug Concessional Co-pay~ A     Alimenta~ A01   STOMATOL~   15327 57011
 3 1991 Sep Concessional Co-pay~ A     Alimenta~ A01   STOMATOL~   14775 55020
 4 1991 Oct Concessional Co-pay~ A     Alimenta~ A01   STOMATOL~   15380 57222
 5 1991 Nov Concessional Co-pay~ A     Alimenta~ A01   STOMATOL~   14371 52120
 6 1991 Dec Concessional Co-pay~ A     Alimenta~ A01   STOMATOL~   15028 54299
 7 1992 Jan Concessional Co-pay~ A     Alimenta~ A01   STOMATOL~   11040 39753
 8 1992 Feb Concessional Co-pay~ A     Alimenta~ A01   STOMATOL~   15165 54405
 9 1992 Mar Concessional Co-pay~ A     Alimenta~ A01   STOMATOL~   16898 61108
10 1992 Apr Concessional Co-pay~ A     Alimenta~ A01   STOMATOL~   18141 65356
# i 67,586 more rows
```

Working with `tsibble` objects

We can use the `filter()` function to select rows.

```
PBS |>
  filter(ATC2 == "A10")
```

```
# A tsibble: 816 x 9 [1M]
# Key:       Concession, Type, ATC1, ATC2 [4]
      Month Concession   Type   ATC1  ATC1_desc ATC2  ATC2_desc Scripts   Cost
      <mth> <chr>        <chr>  <chr> <chr>     <chr> <chr>       <dbl>  <dbl>
 1 1991 Jul Concessional Co-pa~ A     Alimenta~ A10   ANTIDIAB~   89733 2.09e6
 2 1991 Aug Concessional Co-pa~ A     Alimenta~ A10   ANTIDIAB~   77101 1.80e6
 3 1991 Sep Concessional Co-pa~ A     Alimenta~ A10   ANTIDIAB~   76255 1.78e6
 4 1991 Oct Concessional Co-pa~ A     Alimenta~ A10   ANTIDIAB~   78681 1.85e6
 5 1991 Nov Concessional Co-pa~ A     Alimenta~ A10   ANTIDIAB~   70554 1.69e6
 6 1991 Dec Concessional Co-pa~ A     Alimenta~ A10   ANTIDIAB~   75814 1.84e6
 7 1992 Jan Concessional Co-pa~ A     Alimenta~ A10   ANTIDIAB~   64186 1.56e6
 8 1992 Feb Concessional Co-pa~ A     Alimenta~ A10   ANTIDIAB~   75899 1.73e6
 9 1992 Mar Concessional Co-pa~ A     Alimenta~ A10   ANTIDIAB~   89445 2.05e6
```

Working with `tsibble` objects

We can use the `select()` function to select columns.

```
PBS |>
  filter(ATC2 == "A10") |>
  select(Month, Concession, Type, Cost)
```

```
# A tsibble: 816 x 4 [1M]
# Key:       Concession, Type [4]
      Month Concession   Type           Cost
      <mth> <chr>        <chr>         <dbl>
 1 1991 Jul Concessional Co-payments 2092878
 2 1991 Aug Concessional Co-payments 1795733
 3 1991 Sep Concessional Co-payments 1777231
 4 1991 Oct Concessional Co-payments 1848507
 5 1991 Nov Concessional Co-payments 1686458
 6 1991 Dec Concessional Co-payments 1843079
 7 1992 Jan Concessional Co-payments 1564702
 8 1992 Feb Concessional Co-payments 1732508
```

Working with `tsibble` objects

We can use the `summarise()` function to summarise over keys.

```
PBS |>
  filter(ATC2 == "A10") |>
  select(Month, Concession, Type, Cost) |>
  summarise(total_cost = sum(Cost))
```

```
# A tsibble: 204 x 2 [1M]
      Month total_cost
      <mth>      <dbl>
 1 1991 Jul    3526591
 2 1991 Aug    3180891
 3 1991 Sep    3252221
 4 1991 Oct    3611003
 5 1991 Nov    3565869
 6 1991 Dec    4306371
 7 1992 Jan    5088335
 8 1992 Feb    2814520
```

Working with `tsibble` objects

We can use the `mutate()` function to create new variables.

```
PBS |>
  filter(ATC2 == "A10") |>
  select(Month, Concession, Type, Cost) |>
  summarise(total_cost = sum(Cost)) |>
  mutate(total_cost = total_cost / 1e6)
```

```
# A tsibble: 204 x 2 [1M]
      Month total_cost
      <mth>      <dbl>
 1 1991 Jul       3.53
 2 1991 Aug       3.18
 3 1991 Sep       3.25
 4 1991 Oct       3.61
 5 1991 Nov       3.57
 6 1991 Dec       4.31
 7 1992 Jan       5.09
```

Working with `tsibble` objects

We can use the `mutate()` function to create new variables.

```
PBS |>
  filter(ATC2 == "A10") |>
  select(Month, Concession, Type, Cost) |>
  summarise(total_cost = sum(Cost)) |>
  mutate(total_cost = total_cost / 1e6) -> a10
```

```
# A tsibble: 204 x 2 [1M]
      Month total_cost
      <mth>      <dbl>
 1 1991 Jul       3.53
 2 1991 Aug       3.18
 3 1991 Sep       3.25
 4 1991 Oct       3.61
 5 1991 Nov       3.57
 6 1991 Dec       4.31
 7 1992 Jan       5.09
```