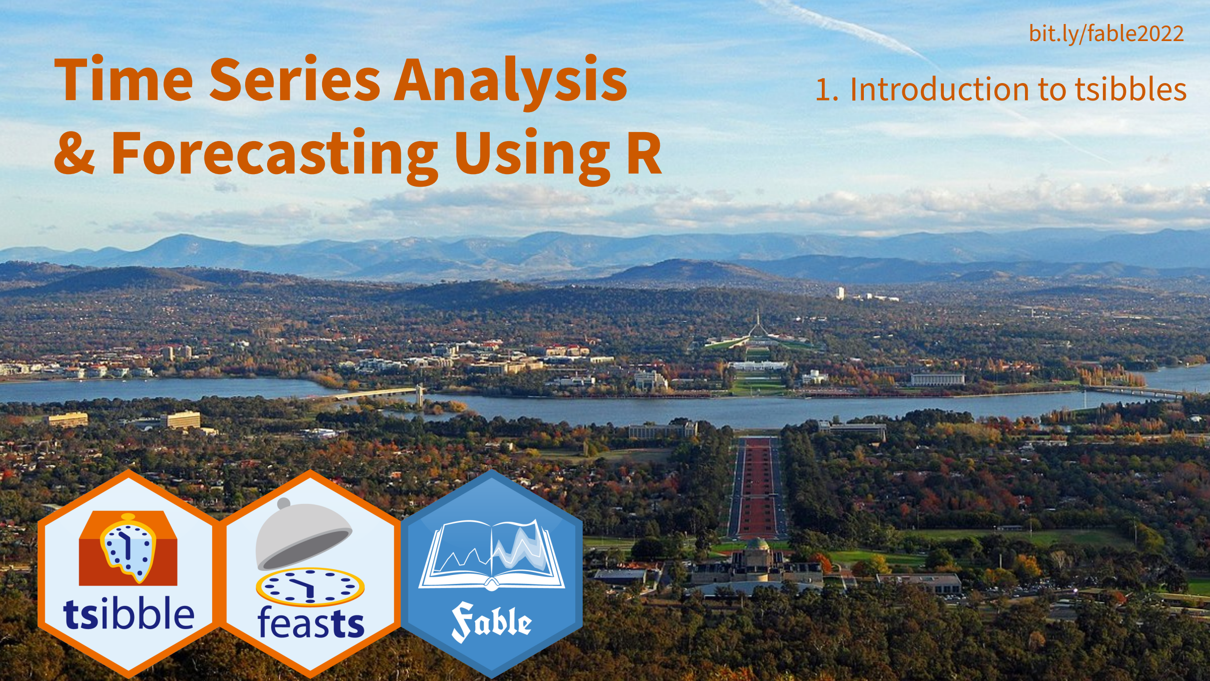

bit.ly/fable2022

Time Series Analysis & Forecasting Using R

1. Introduction to tsibbles

tsibble feasts Fable

Outline

1 Time series data and tsibbles

2 Example: Australian prison population

3 Example: Australian pharmaceutical sales

4 Lab Session 1

5 Time plots

6 Lab Session 2

Outline

1. Time series data and tsibbles
2. Example: Australian prison population
3. Example: Australian pharmaceutical sales
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5. Time plots
6. Lab Session 2

Tidyverts packages

tidyverts.org

Tidyverts developers

Earo Wang

Mitchell O’Hara-Wild

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

```r
# Data manipulation and plotting functions
library(tidyverse)
# Time series manipulation
library(tsibble)
# Forecasting functions
library(fable)
# Time series graphics and statistics
library(feasts)
# Tidy time series data
library(tsibbledata)
```

Class packages

```
# Data manipulation and plotting functions
library(tidyverse)
# Time series manipulation
library(tsibble)
# Forecasting functions
library(fable)
# Time series graphics and statistics
library(feasts)
# Tidy time series data
library(tsibbledata)
```

```
# All of the above and more
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]
##     Year Country              GDP Imports Exports Population
##    Index <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]
##     Year Country             GDP Imports Exports Population
##    Index Key               <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]
##     Year Country                GDP Imports Exports Population
##      Index Key          Measured variables                   bl>
##  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.
```

tsibble objects

```
tourism
```

```
## # A tsibble: 24,320 x 5 [1Q]
## # Key:       Region, State, Purpose [304]
##    Quarter Region   State Purpose  Trips
##     Index  > <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.
```

tsibble objects

```
tourism
```

```
## # A tsibble: 24,320 x 5 [1Q]
## # Key:       Region, State, Purpose [304]
##    Quarter Region   State Purpose  Trips
##    Index   > Keys                  <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.
```

tsibble objects

```
tourism
```

```
## # A tsibble: 24,320 x 5 [1Q]
## # Key:       Region, State, Purpose [304]
##    Quarter Region   State Purpose  Trips
##    Index  > Keys                   Measure
##  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.
```

tsibble objects

```r
tourism
```

```
## # A tsibble: 24,320 x 5 [1Q]
## # Key:       Region, State, Purpose [304]
##    Quarter Region   State Purpose  Trips
##    Index   > Keys                  Measure
##  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.
```

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()`

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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
## # … with 3,062 more rows
```

Read a csv file and convert to a tsibble

```r
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
## # ... with 3,062
```

Read a csv file and convert to a tsibble

```r
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

```r
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
```

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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
## # ... with 67,586 more rows
```

Working with `tsibble` objects

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

```r
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
```

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Lab Session 1

1. Download `tourism.xlsx` from `http://robjhyndman.com/data/tourism.xlsx`, and read it into R using `read_excel()` from the `readxl` package.
2. Create a tsibble which is identical to the `tourism` tsibble from the `tsibble` package.
3. Find what combination of `Region` and `Purpose` had the maximum number of overnight trips on average.
4. Create a new tsibble which combines the Purposes and Regions, and just has total trips by State.

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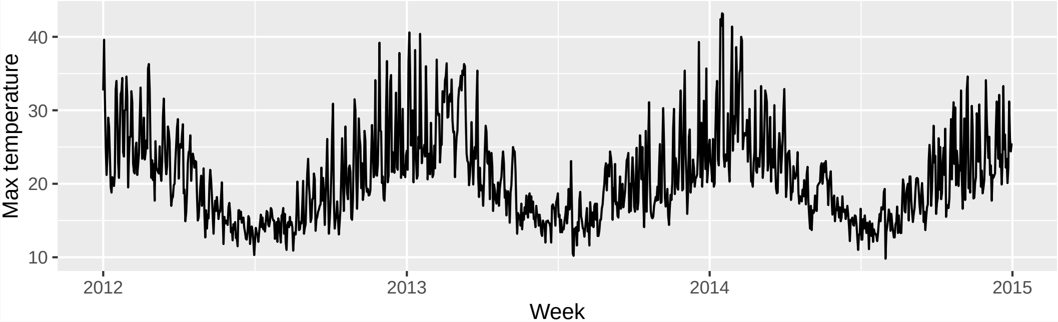
Time plots

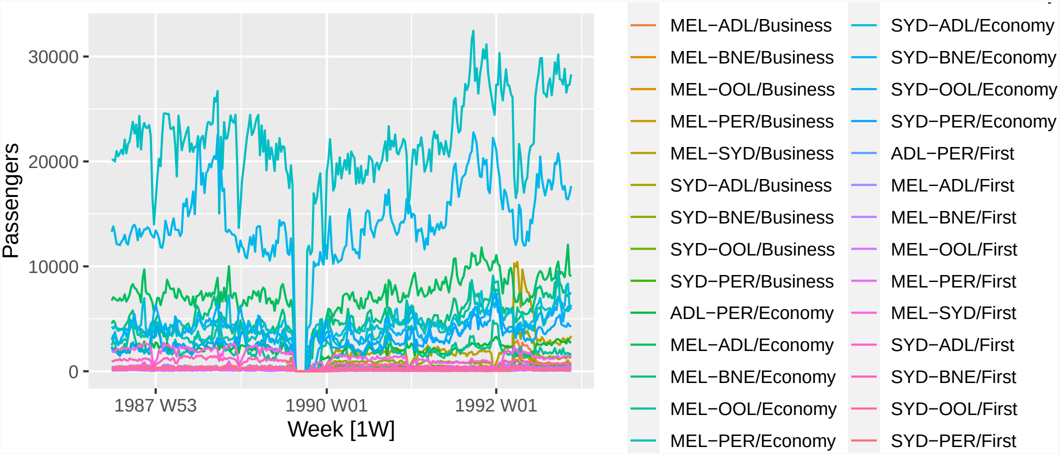
```
maxtemp <- vic_elec ▷
  index_by(Day = date(Time)) ▷
  summarise(Temperature = max(Temperature))
maxtemp ▷
  autoplot(Temperature) +
  labs(x = "Week", y = "Max temperature")
```



Ansett airlines

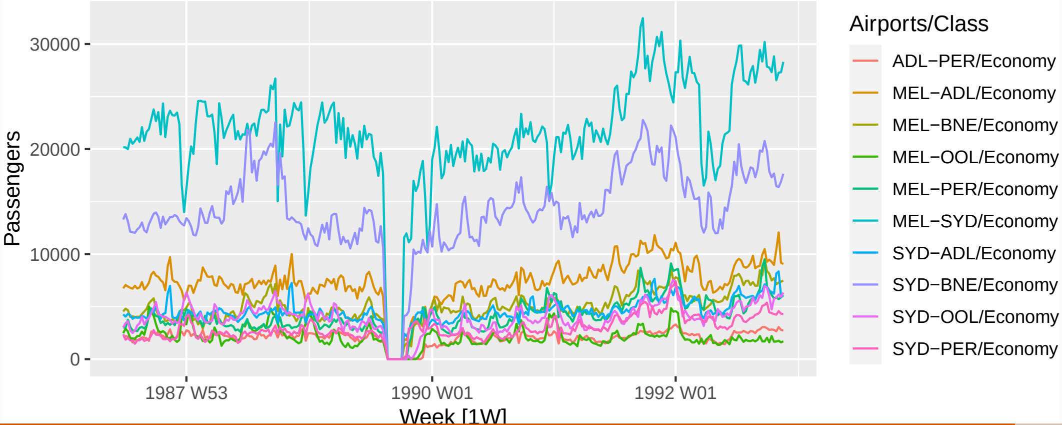
Ansett airlines

```
ansett |>
  autoplot(Passengers)
```



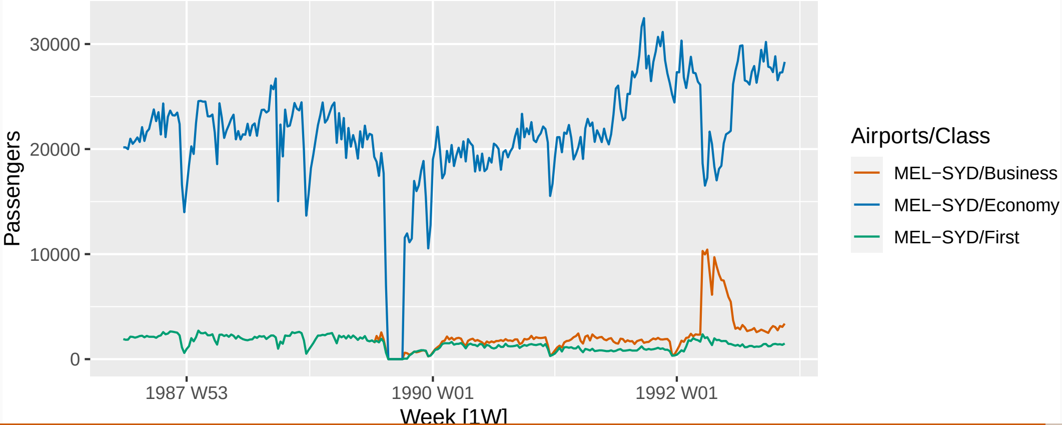
Ansett airlines

```r
ansett |>
  filter(Class == "Economy") |>
  autoplot(Passengers)
```



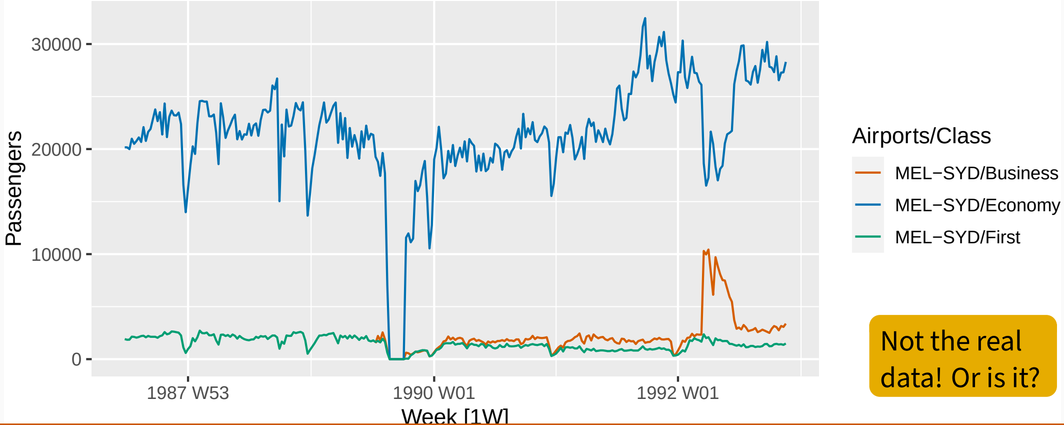
Ansett airlines

```r
ansett |>
  filter(Airports == "MEL-SYD") |>
  autoplot(Passengers)
```



Ansett airlines

```
ansett ▷
  filter(Airports == "MEL-SYD") ▷
  autoplot(Passengers)
```



Not the real data! Or is it?

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6. Lab Session 2

Lab Session 2

- Create time plots of the following four time series: `Bricks` from `aus_production`, `Lynx` from `pelt`, `Close` from `gafa_stock`, `Demand` from `vic_elec`.
- Use `help()` to find out about the data in each series.
- For the last plot, modify the axis labels and title.