Time Series Analysis & Forecasting Using R

1. Introduction to tsibbles

bit.ly/tidyts2023

Photo by Max Bender on Unsplash

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

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

```
# 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
# i 15,140 more rows
```

`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
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# i 15,140 more rows
```

`tsibble` objects

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global_economy
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```
# 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
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 6  1965 Afghanistan 1006666638.   21.4    11.3     9938414
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`tsibble` objects

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# Key:       Country [263]
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   1960 Afghanistan  537777811.     7.02    4.13    8996351
   1961 Afghanistan  548888896.     8.10    4.45    9166764
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   1963 Afghanistan  751111191.    16.9     9.17    9533954
   1964 Afghanistan  800000044.    18.1     8.89    9731361
   1965 Afghanistan 1006666638.    21.4    11.3     9938414
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   1968 Afghanistan 1373333367.    15.2     8.90   10604346
   1969 Afghanistan 1408888922.    15.0    10.1    10854428
# i 15,140 more rows
```

Index Key Measured variables

`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
     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.
# i 24,310 more rows
```

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]
   Quarter Region   State Purpose  Trips
   Index   Keys                    <dbl>
 1 1998 Q1 Adelaide SA    Business  135.
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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]
   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.
# 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
# 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) |>
  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
 6 ACT   Female Remanded ATSI           1 2006 Q2
```

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
10 1992 Apr Concessional Co-pa~ A     Alimenta~ A10   ANTIDIAB~   97315 2.23e6
```

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
 9 1992 Mar Concessional Co-payments 2046102
```

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
 9 1992 Mar    2985811
```

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
 8 1992 Feb       2.81
```

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
 8 1992 Feb       2.81
```

Outline

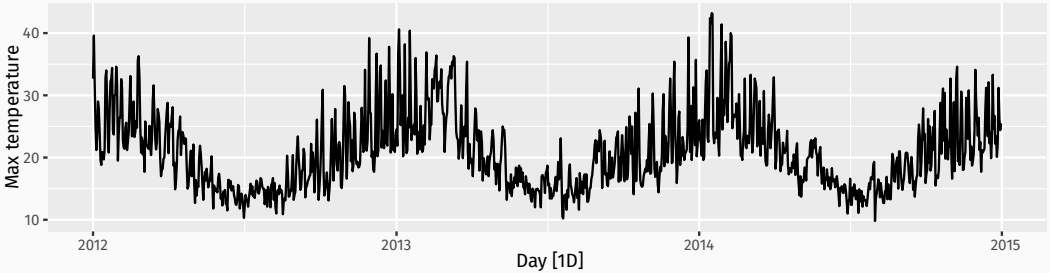
Lab Session 1

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.

Outline

Time plots

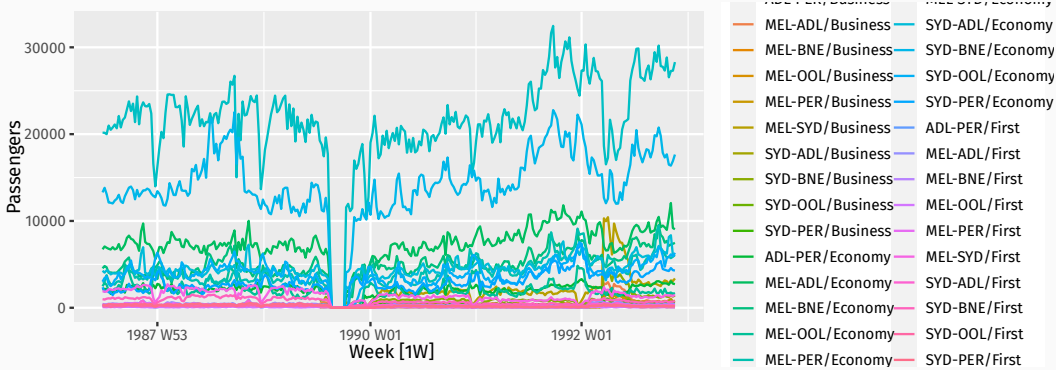
```
maxtemp <- vic_elec |>
  index_by(Day = date(Time)) |>
  summarise(Temperature = max(Temperature))
maxtemp |>
  autoplot(Temperature) +
  labs(y = "Max temperature")
```



Ansett airlines

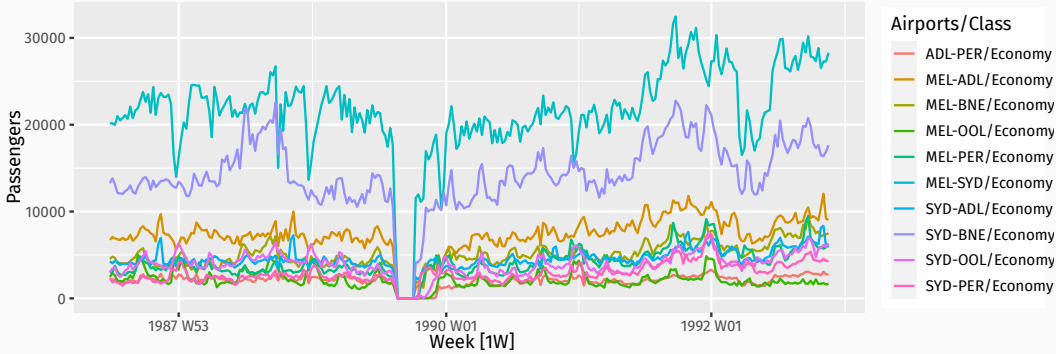
Ansett airlines

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



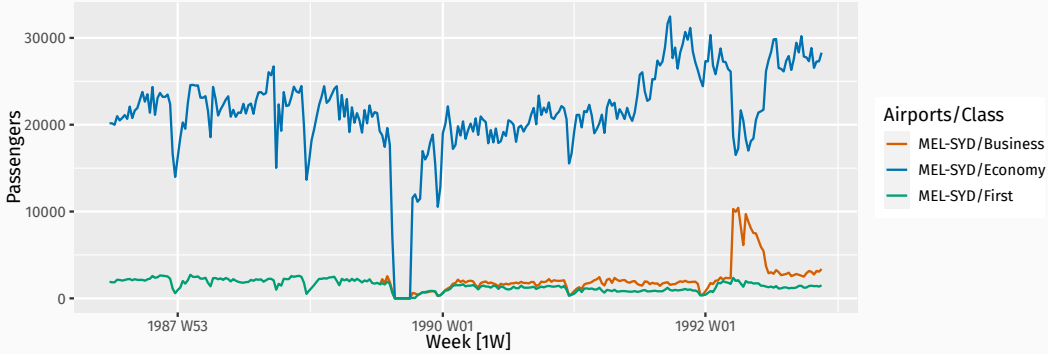
Ansett airlines

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



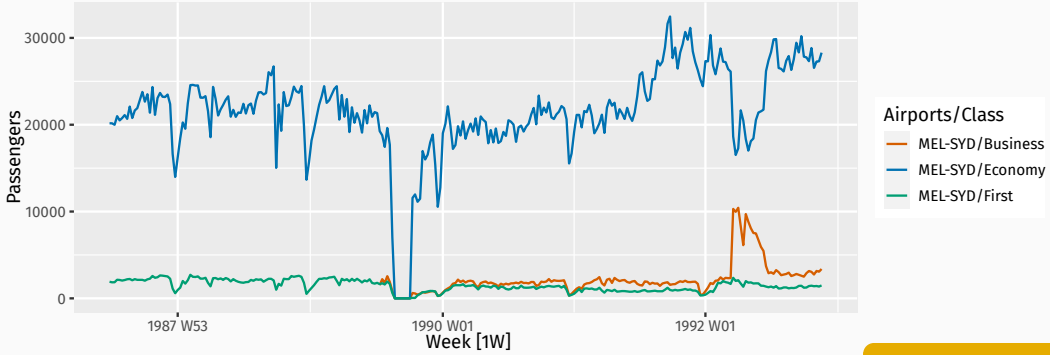
Ansett airlines

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



Ansett airlines

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



Not the real data! Or is it?

Outline

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.