

Time Series Analysis & Forecasting Using R

bit.ly/fable2023

1. Introduction to tsibbles



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

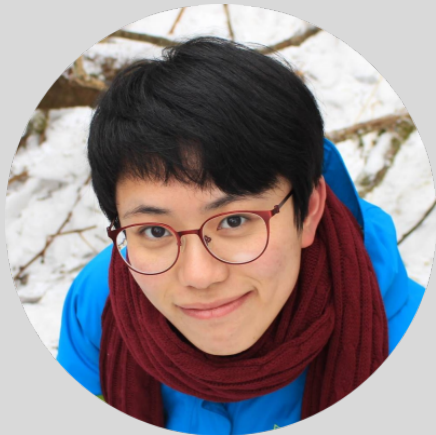
Outline

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



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
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	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

```
# 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	Key	Measured variables			
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

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
```

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
   <dbl>   <dbl> <dbl>   <dbl> <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	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	<code>start:end</code>
Quarterly	<code>yearquarter()</code>
Monthly	<code>yearmonth()</code>
Weekly	<code>yearweek()</code>
Daily	<code>as_date()</code> , <code>ymd()</code>
Sub-daily	<code>as_datetime()</code>

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

Australian prison population



Read a csv file and convert to a tibble

```
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 tibble

```
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 tibble

```
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

- 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

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
   <mt>  <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

- 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

Lab Session 1

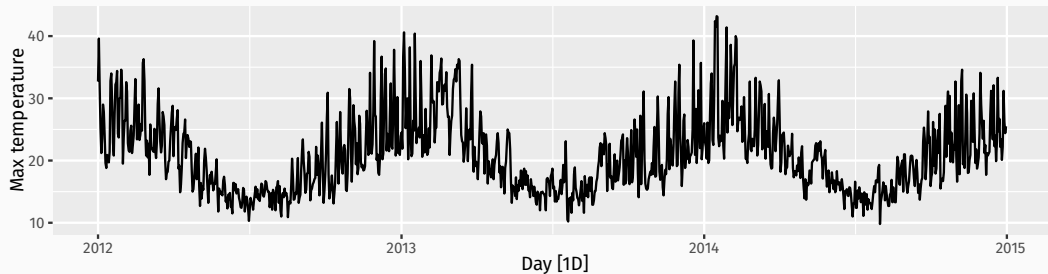
- 1 Download `tourism.xlsx` from <http://robjhyndman.com/data/tourism.xlsx>, and read it into R using `read_excel()` from the `readxl` package.
- 2 Create a `tsibble` which is identical to the `tourism` `tsibble` from the `tsibble` package.
- 3 Find what combination of `Region` and `Purpose` had the 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

- 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

Time plots

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



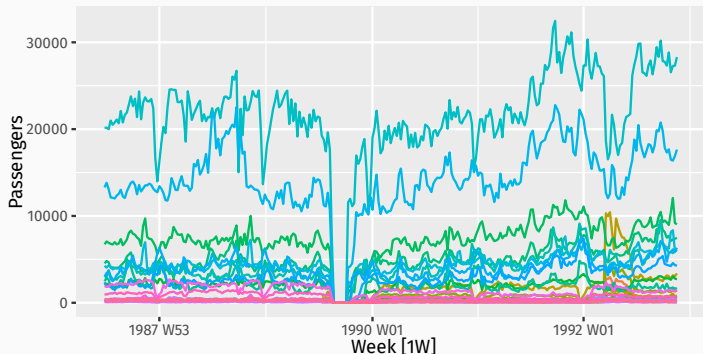
Ansett airlines



Ansett airlines

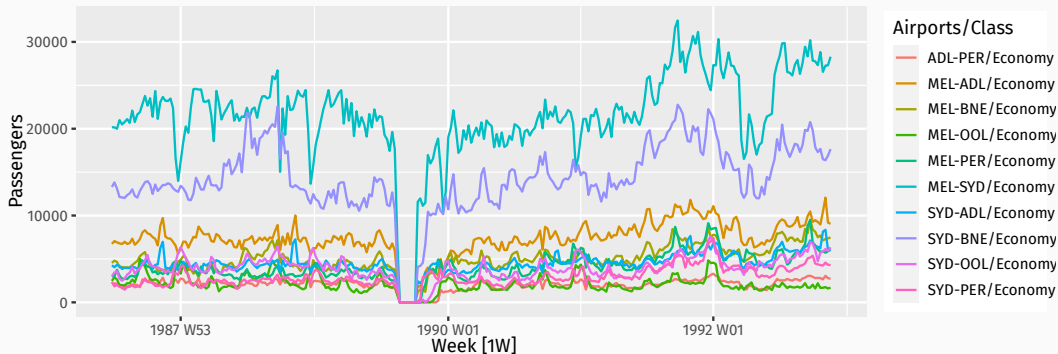
```
ansett |>
```

```
autoplot(Passengers)
```



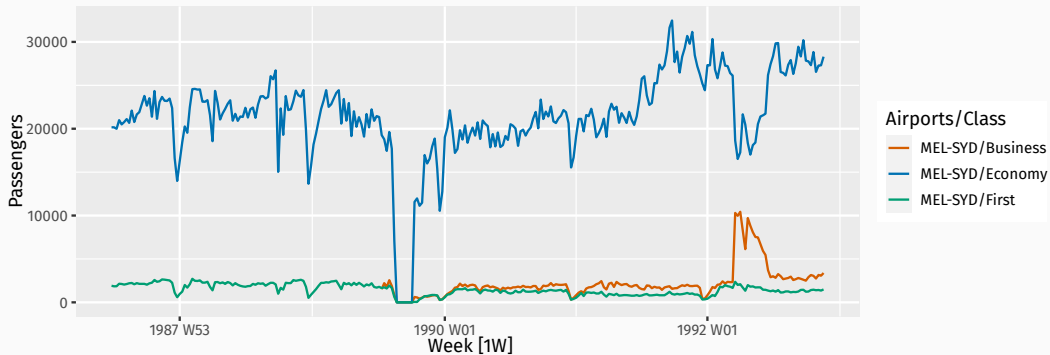
Ansett airlines

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



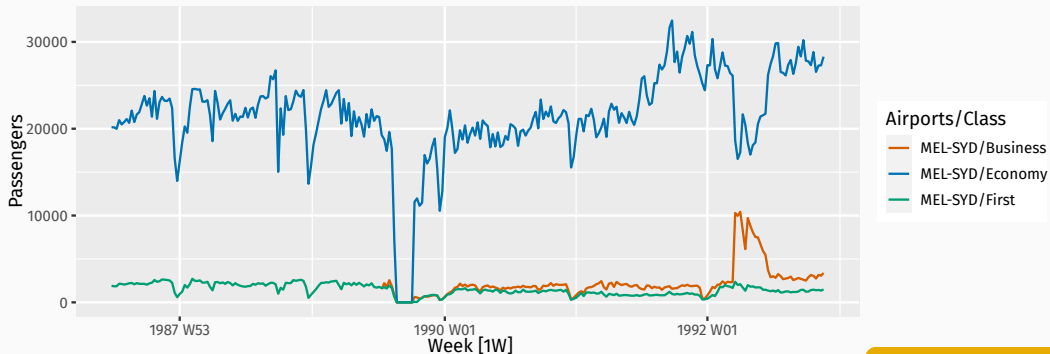
Ansett airlines

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



Ansett airlines

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



Not the real
data! Or is it?

Outline

- 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

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.