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FORECASTING

PRINCIPLES AND PRACTICE

A comprehensive introduction to the latest forecasting methods using R. Learn to improve your forecast accuracy using dozens of real data examples.



3RD EDITION

 **OTexts**
Open Texts Publishing

2. Time series graphics

2.1 tsibble objects

OTexts.org/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

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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	<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

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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
##	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
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```
## # 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
```

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

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```
## # 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

Example

```
mydata <- tibble(  
  year = 2012:2016,  
  y = c(123, 39, 78, 52, 110)  
) |>  
  as_tsibble(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
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>

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
## # ... with 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

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
```

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
```

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_~1 ATC2  ATC2_~2 Scripts  Cost
##      <mt> <chr>      <chr>      <chr> <chr>    <chr> <chr>    <dbl> <dbl>
##  1 1991 Jul Concessional Co-payments A      Alimen~ A01    STOMAT~ 18228 67877
##  2 1991 Aug Concessional Co-payments A      Alimen~ A01    STOMAT~ 15327 57011
##  3 1991 Sep Concessional Co-payments A      Alimen~ A01    STOMAT~ 14775 55020
##  4 1991 Oct Concessional Co-payments A      Alimen~ A01    STOMAT~ 15380 57222
##  5 1991 Nov Concessional Co-payments A      Alimen~ A01    STOMAT~ 14371 52120
##  6 1991 Dec Concessional Co-payments A      Alimen~ A01    STOMAT~ 15028 54299
##  7 1992 Jan Concessional Co-payments A      Alimen~ A01    STOMAT~ 11040 39753
##  8 1992 Feb Concessional Co-payments A      Alimen~ A01    STOMAT~ 15165 54405
##  9 1992 Mar Concessional Co-payments A      Alimen~ A01    STOMAT~ 16898 61108
## 10 1992 Apr Concessional Co-payments A      Alimen~ A01    STOMAT~ 18141 65356
## # ... with 67,586 more rows, and abbreviated variable names 1: ATC1_desc,
## #      2: ATC2_desc
```

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_~1 ATC2 ATC2_~2 Scripts Cost  
##   <mtch> <chr>      <chr> <chr> <chr> <chr> <chr> <dbl> <dbl>  
## 1 1991 Jul Concessional Co-paymen~ A Alimen~ A10 ANTIDI~ 89733 2.09e6  
## 2 1991 Aug Concessional Co-paymen~ A Alimen~ A10 ANTIDI~ 77101 1.80e6  
## 3 1991 Sep Concessional Co-paymen~ A Alimen~ A10 ANTIDI~ 76255 1.78e6  
## 4 1991 Oct Concessional Co-paymen~ A Alimen~ A10 ANTIDI~ 78681 1.85e6  
## 5 1991 Nov Concessional Co-paymen~ A Alimen~ A10 ANTIDI~ 70554 1.69e6  
## 6 1991 Dec Concessional Co-paymen~ A Alimen~ A10 ANTIDI~ 75814 1.84e6  
## 7 1992 Jan Concessional Co-paymen~ A Alimen~ A10 ANTIDI~ 64186 1.56e6  
## 8 1992 Feb Concessional Co-paymen~ A Alimen~ A10 ANTIDI~ 75899 1.73e6  
## 9 1992 Mar Concessional Co-paymen~ A Alimen~ A10 ANTIDI~ 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(TotalC = sum(Cost))
```

```
## # A tsibble: 204 x 2 [1M]
```

```
##       Month  TotalC
```

```
##       <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(TotalC = sum(Cost)) |>
  mutate(Cost = TotalC / 1e6)
```

```
## # A tsibble: 204 x 3 [1M]
##       Month  TotalC  Cost
##       <mth>   <dbl> <dbl>
## 1 1991 Jul  3526591  3.53
## 2 1991 Aug  3180891  3.18
## 3 1991 Sep  3252221  3.25
## 4 1991 Oct  3611003  3.61
## 5 1991 Nov  3565869  3.57
## 6 1991 Dec  4306371  4.31
## 7 1992 Jan  5088335  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(TotalC = sum(Cost)) |>
  mutate(Cost = TotalC / 1e6) -> a10
```

```
## # A tsibble: 204 x 3 [1M]
##       Month  TotalC  Cost
##       <mth>   <dbl> <dbl>
## 1 1991 Jul  3526591  3.53
## 2 1991 Aug  3180891  3.18
## 3 1991 Sep  3252221  3.25
## 4 1991 Oct  3611003  3.61
## 5 1991 Nov  3565869  3.57
## 6 1991 Dec  4306371  4.31
## 7 1992 Jan  5088335  5.09
```