

HAMBURG SCHOOL OF BUSINESS ADMINISTRATION

Digital Tool Box – Project Report

Project work as part of the Bachelor of Science (B.Sc.) in
Media Management & Communication and Business Informatics

Tania Testperson (XXXX)
Max Mustermann (XXXX)

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Abstract

The present specialized bookdown project template you are using now is intended as the basis for a report or thesis at the Hamburg School of Business Administration (HSBA). Compared to the original project template coming with the bookdown package, it generates PDF output only, using a slightly customized LaTeX template based on the original Pandoc-template, which is adapted to the requirements of the HSBA for theses and reports. The main notable differences are an appropriate title page, an automatic word count function, a list of acronyms, an adapted page numbering, the use of the appropriate Chicago Manual of Style citation style (17th edition, CSL-based) and an additional chapter with a basic declaration of honor at the end. In addition, several additional folders are used to demonstrate a basic project structure, as well as a slightly modified file organization to show the use of other R packages in addition to the bookdown basics. The contents of the original bookdown template can be found in the following chapters, the additional code examples in the appendix. For more information about this template, please refer to the file 'README.md'.

Contents

Abstract	i
Contents	ii
List of Figures	iii
List of Tables	iii
Acronyms	v
1 About	1
1.1 Usage	1
1.2 Render book	1
1.3 Preview book	2
2 Hello bookdown	3
2.1 A section	3
An unnumbered section	3
3 Cross-references	5
3.1 Chapters and sub-chapters	5
3.2 Captioned figures and tables	5
4 Parts	9
5 Footnotes and citations	11
5.1 Footnotes	11
5.2 Citations	11
6 Blocks	13
6.1 Equations	13
6.2 Theorems and proofs	13
6.3 Callout blocks	13
7 Sharing your book	15
7.1 Publishing	15
7.2 404 pages	15
7.3 Metadata for sharing	15
References	17
Declaration of Honor	19

A	Useful code examples	21
A.1	Use of acronyms	21
A.2	Load packages and read data into R	21
A.3	Displaying different types of tables from modelsummary	23
A.4	Reporting statistical models	26
A.4.1	t -test	26
A.4.2	χ^2 -test	27
A.4.3	Linear regression models	28
A.4.4	Generalized linear regression models	33
A.4.5	Automated report generation	38
A.5	Plotting statistical models	40
B	Data-set	45

List of Figures

Fig. 3.1	Here is a nice figure!	6
Fig. A.1	Predicted probabilities of survival for each passenger class	41
Fig. A.2	Predicted probabilities of survival dependend on sex and age	42
Fig. A.3	One overall plot with four subplots	44

List of Tables

Tbl. 3.1	Here is a nice table!	7
Tbl. A.1	Overview of the numerical variables in data set df1	24
Tbl. A.2	Correlations of numerical variables in data set df1	24
Tbl. A.3	Cross tabulations for year and type of drive	25
Tbl. A.4	Analysis of variance table for three linear models	29
Tbl. A.5	Comparison of three linear models using modelsummary	31
Tbl. A.6	Comparison of three linear models using stargazer	32
Tbl. A.7	A logistic regression model for the titanic data set using package jtools . . .	36
Tbl. A.8	A logistic regression model for the titanic data set using package gtsummary	37

Acronyms

CRAN	Comprehensive R Archive Network
H₂O	water
IDE	integrated development environment
GLM	generalized linear model

1. About

This is a *sample* book written in **Markdown**. You can use anything that Pandoc's Markdown supports; for example, a math equation $a^2 + b^2 = c^2$.

1.1. Usage

Each **bookdown** chapter is an .Rmd file, and each .Rmd file can contain one (and only one) chapter. A chapter *must* start with a first-level heading: # A good chapter, and can contain one (and only one) first-level heading.

Use second-level and higher headings within chapters like: ## A short section or ### An even shorter section.

The index.Rmd file is required, and is also your first book chapter. It will be the homepage when you render the book.

1.2. Render book

You can render the HTML version of this example book without changing anything:

1. Find the **Build** pane in the RStudio IDE, and
2. Click on **Build Book**, then select your output format, or select "All formats" if you'd like to use multiple formats from the same book source files.

Or build the book from the R console:

```
bookdown::render_book()
```

To render this example to PDF as a `bookdown::pdf_book`, you'll need to install XeLaTeX. You are recommended to install TinyTeX (which includes XeLaTeX): <https://yihui.org/tinytex/>.

1.3. Preview book

As you work, you may start a local server to live preview this HTML book. This preview will update as you edit the book when you save individual `.Rmd` files. You can start the server in a work session by using the RStudio add-in “Preview book”, or from the R console:

```
bookdown::serve_book()
```


2. Hello bookdown

All chapters start with a first-level heading followed by your chapter title, like the line above. There should be only one first-level heading (#) per .Rmd file.

2.1. A section

All chapter sections start with a second-level (##) or higher heading followed by your section title, like the sections above and below here. You can have as many as you want within a chapter.

An unnumbered section

Chapters and sections are numbered by default. To un-number a heading, add a `{.unnumbered}` or the shorter `{-}` at the end of the heading, like in this section.

3. Cross-references

Cross-references make it easier for your readers to find and link to elements in your book.

3.1. Chapters and sub-chapters

There are two steps to cross-reference any heading:

1. Label the heading: `# Hello world {#nice-label}`.
 - Leave the label off if you like the automated heading generated based on your heading title: for example, `# Hello world = # Hello world {#hello-world}`.
 - To label an un-numbered heading, use: `# Hello world {-#nice-label}` or `{# Hello world .unnumbered}`.
2. Next, reference the labeled heading anywhere in the text using `\@ref(nice-label)`; for example, please see Chapter 3.
 - If you prefer text as the link instead of a numbered reference use: any text you want can go here.

3.2. Captioned figures and tables

Figures and tables *with captions* can also be cross-referenced from elsewhere in your book using `\@ref(fig:chunk-label)` and `\@ref(tab:chunk-label)`, respectively.

See Figure 3.1.

```
par(mar = c(4, 4, .1, .1))  
plot(pressure, type = 'b', pch = 19)
```

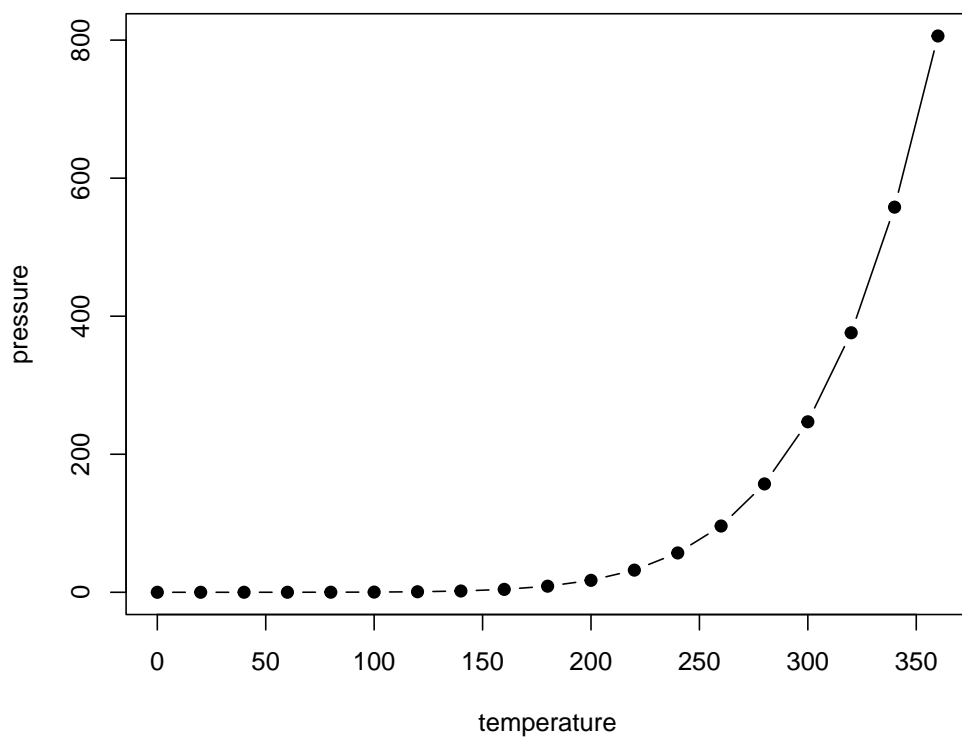


Figure 3.1.: Here is a nice figure!

Don't miss Table 3.1.

```
knitr::kable(  
  head(pressure, 10), caption = 'Here is a nice table!'  
  , booktabs = TRUE  
)
```

Table 3.1.: Here is a nice table!

temperature	pressure
0	0.0002
20	0.0012
40	0.0060
60	0.0300
80	0.0900
100	0.2700
120	0.7500
140	1.8500
160	4.2000
180	8.8000

4. Parts

You can add parts to organize one or more book chapters together. Parts can be inserted at the top of an .Rmd file, before the first-level chapter heading in that same file.

Add a numbered part: `# (PART) Act one {-}` (followed by `# A chapter`)

Add an unnumbered part: `# (PART*) Act one {-}` (followed by `# A chapter`)

Add an appendix as a special kind of un-numbered part: `# (APPENDIX) Other stuff {-}` (followed by `# A chapter`). Chapters in an appendix are prepended with letters instead of numbers.

5. Footnotes and citations

5.1. Footnotes

Footnotes are put inside the square brackets after a caret `^[]`. Like this one ¹.

5.2. Citations

Reference items in your bibliography file(s) using @key.

For example, we are using the **bookdown** package (Xie 2022) (check out the last code chunk in index.Rmd to see how this citation key was added) in this sample book, which was built on top of R Markdown and **knitr** (Xie 2015) (this citation was added manually in an external file book.bib). Note that the .bib files need to be listed in the index.Rmd with the YAML bibliography key.

The RStudio Visual Markdown Editor can also make it easier to insert citations: <https://rstudio.github.io/visual-markdown-editing/#/citations>

¹This is a footnote.

6. Blocks

6.1. Equations

Here is an equation.

$$f(k) = \binom{n}{k} p^k (1-p)^{n-k} \quad (6.1)$$

You may refer to using `\@ref(eq:binom)`, like see Equation (6.1).

6.2. Theorems and proofs

Labeled theorems can be referenced in text using `\@ref(thm:tri)`, for example, check out this smart theorem 6.1.

Theorem 6.1. *For a right triangle, if c denotes the length of the hypotenuse and a and b denote the lengths of the **other** two sides, we have*

$$a^2 + b^2 = c^2$$

Read more here <https://bookdown.org/yihui/bookdown/markdown-extensions-by-bookdown.html>.

6.3. Callout blocks

The R Markdown Cookbook provides more help on how to use custom blocks to design your own callouts: <https://bookdown.org/yihui/rmarkdown-cookbook/custom-blocks.html>

7. Sharing your book

7.1. Publishing

HTML books can be published online, see: <https://bookdown.org/yihui/bookdown/publishing.html>

7.2. 404 pages

By default, users will be directed to a 404 page if they try to access a webpage that cannot be found. If you'd like to customize your 404 page instead of using the default, you may add either a `_404.Rmd` or `_404.md` file to your project root and use code and/or Markdown syntax.

7.3. Metadata for sharing

Bookdown HTML books will provide HTML metadata for social sharing on platforms like Twitter, Facebook, and LinkedIn, using information you provide in the `index.Rmd` YAML. To setup, set the `url` for your book and the path to your `cover-image` file. Your book's title and description are also used.

This gitbook uses the same social sharing data across all chapters in your book- all links shared will look the same.

Specify your book's source repository on GitHub using the `edit` key under the configuration options in the `_output.yml` file, which allows users to suggest an edit by linking to a chapter's source file.

Read more about the features of this output format here:

<https://pkgs.rstudio.com/bookdown/reference/gitbook.html>

7. *Sharing your book*

Or use:

```
?bookdown::gitbook
```

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Declaration of Honor

We hereby declare that

1. we wrote this project report without the assistance of others;
2. we have marked direct quotes used from the literature and the use of ideas of other authors at the corresponding locations in the thesis;
3. we have not presented this thesis for any other exam. We acknowledge that a false declaration will have legal consequences.

Hamburg, dd.mm.yyyy

aaaaa, bbbbbb

We accept that the HSBA may check the originality of our work using a range of manual and computer based techniques, including transferring and storing our submission in a database for the purpose of data-matching to help detect plagiarism.

Hamburg, dd.mm.yyyy

aaaaa, bbbbbb

A. Useful code examples

A.1. Use of acronyms

To begin, let's see how the list of acronyms is working. The acronyms are defined in the file `abbreviations.tex`, see an explanation of how to do that in the file itself. Regarding the use of these acronyms inside of the text: In the source code, one writes something as follows, using standard \LaTeX commands:

First use: `\Ac{cran}`. Second use: `\ac{cran}`. First use of another abbreviation: `\ac{ide}`, then the plural use: `\acp{ide}`. And here you see that `\acs{H2O}` is actually `\ac{H2O}`.

This displays as follows:

First use: Comprehensive R Archive Network (CRAN). Second use: CRAN. First use of another abbreviation: integrated development environment (IDE), then the plural use: IDEs. And here you see that H_2O is actually water (H_2O).

A.2. Load packages and read data into R

At the beginning of your book, you should put all necessary packages in one chunk, then loading the data in the next chunk so that these steps are properly organized:

```
library(tidyverse) # This includes readr!
library(xtable) # For displaying LaTeX tables
library(modelsummary) # For displaying regression models in tables
library(stargazer) # For displaying regression models in tables
library(jtools) # For displaying regression models in tables
library(kableExtra) # For displaying or changing tables
library(gt) # For displaying tables
```

```
library(gtsummary) # For model reporting inline and in tables
library(broom) # For working with statistical models
library(car) # For type-III anova tests
library(report) # For automated text-based model reporting
library(effects) # For working with statistical models / visualize effects
library(ggeffects) # For working with statistical models / visualize effects
library(patchwork) # For putting different visualizations in one figure
```

One of the most common ways to get your data into R is to place them into your project directory as a CSV-file and read them into the current session, that is, the session of the produced book, using `readr` (<https://cran.r-project.org/web/packages/readr/>).

```
df1 <- read_csv("02-data/mpg_data_as_csv.csv", lazy = FALSE)
```

```
#> Rows: 234 Columns: 11
#> -- Column specification -----
#> Delimiter: ","
#> chr (6): manufacturer, model, trans, drv, fl, class
#> dbl (5): displ, year, cyl, cty, hwy
#>
#> i Use `spec()` to retrieve the full column specification for this data.
#> i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

You can then use the function arguments to change necessary things like the delimiter (also switching to `readr::read_delim()` instead of `readr::read_csv()` to do this), or see the specifics of the column types using `readr::spec()` and change them accordingly if needed.

```
spec(df1)
```

```
#> cols(
#>   manufacturer = col_character(),
#>   model = col_character(),
#>   displ = col_double(),
#>   year = col_double(),
#>   cyl = col_double(),
#>   trans = col_character(),
#>   drv = col_character(),
#>   cty = col_double(),
#>   hwy = col_double(),
#>   fl = col_character(),
#>   class = col_character()
#> )
```






```
df1 <- read_delim("02-data/mpg_data_as_csv.csv",
                  delim = ",",
                  col_types = cols(
                    manufacturer = col_character(),
                    model = col_character(),
                    displ = col_double(),
                    year = col_double(),
                    cyl = col_double(),
                    trans = col_character(),
                    drv = col_character(),
                    cty = col_double(),
                    hwy = col_double(),
                    fl = col_character(),
                    class = col_character()
                  ), lazy = FALSE
)
```

A.3. Displaying different types of tables from modelsummary

The data set is part of the `ggplot2` package (<https://cran.r-project.org/web/packages/ggplot2/>) and is originally named `mpg`. To display a summary of the data set in your work, you may use, for example, the `modelsummary` package with its function `modelsummary::datasummary_skim()`, from which the output can be seen in table A.1. Don't forget to name the chunk and specify the table caption using the argument `title` in the function call! Without these two adjustments, you cannot cross-reference this table and it does not appear in the list of tables in the frontmatter. Another source of error is the naming of the chunks: Never use underscores in these, only letters and minus signs! And always place a blank line in front and after a code chunk.

```
# You can reference this table now with "@ref(tab:skim-df1)".
# The part with kable_styling is coming from the kableExtra package and
# changes the position of the table and its appearance
datasummary_skim(df1, output = 'kableExtra', booktabs = TRUE,
                  title = "Overview of the numerical variables in data set df1") %>%
  kable_styling(latex_options = c("striped", "HOLD_position"))
```

Table A.1.: Overview of the numerical variables in data set df1

	Unique (#)	Missing (%)	Mean	SD	Min	Median	Max	
displ	35	0	3.5	1.3	1.6	3.3	7.0	
year	2	0	2003.5	4.5	1999.0	2003.5	2008.0	
cyl	4	0	5.9	1.6	4.0	6.0	8.0	
cty	21	0	16.9	4.3	9.0	17.0	35.0	
hwy	27	0	23.4	6.0	12.0	24.0	44.0	

Another useful table can be produced by using the function `datasummary_correlation()` from the same package. Its output can be seen in table A.2, which in addition is changed to show how to use footnotes using `kableExtra`. The content of the footnote is also true for table A.1, so be careful and adjust variable types before doing something with them such as in table A.3.

```
df1_footnote <- df1
names(df1_footnote)[names(df1_footnote) == "year"] <-
  paste0(names(df1_footnote)[names(df1_footnote) == "year"],
    footnote_marker_symbol(1, "latex"))

datasummary_correlation(df1_footnote, output = 'kableExtra',
  booktabs = TRUE, escape = FALSE, # 'escape = FALSE' here is important!
  title = "Correlations of numerical variables in data set df1") %>%
  kable_styling(latex_options = c("striped", "HOLD_position")) %>%
  footnote(symbol = paste0("Using the categorical variable",
    " 'year' here in a correlation is :-("),
    threeparttable = TRUE) # This last options enables the line break!
```

Table A.2.: Correlations of numerical variables in data set df1

	displ	year*	cyl	cty	hwy
displ	1
year*	0.15	1	.	.	.
cyl	0.93	0.12	1	.	.
cty	-0.80	-0.04	-0.81	1	.
hwy	-0.77	0.00	-0.76	0.96	1

* Using the categorical variable 'year' here in a correlation is :-(

Adjusting all categorical variables to the correct type:

```
df1 <- df1 %>%
  mutate(manufacturer = factor(manufacturer),
         model = factor(model),
         year = factor(year),
         cyl = ordered(cyl,
                       levels = c(4,5,6,8),
                       labels = c("4 Cylinders",
                                  "5 Cylinders",
                                  "6 Cylinders",
                                  "8 Cylinders")),
         trans = factor(trans),
         drv = factor(drv,
                      levels = c("f", "r", "4"),
                      labels = c("Front wheel drive",
                                  "Rear wheel drive",
                                  "4 wheel drive")),
         fl = factor(fl),
         class = factor(class))
```

Now using another kind of table from the modelsummary package:

```
datasummary_crosstab(drv ~ year,
                     data = df1, booktabs = TRUE,
                     title = "Cross tabulations for year and type of drive") %>%
  kable_styling(latex_options = c("striped", "HOLD_position"))
```

Table A.3.: Cross tabulations for year and type of drive

drv		1999	2008	All
Front wheel drive	N	57	49	106
	% row	53.8	46.2	100.0
Rear wheel drive	N	11	14	25
	% row	44.0	56.0	100.0
4 wheel drive	N	49	54	103
	% row	47.6	52.4	100.0
All	N	117	117	234
	% row	50.0	50.0	100.0

See the datasummary vignettes for more possibilities:

<https://vincentarelbundock.github.io/modelsummary/articles/datasummary.html>

A.4. Reporting statistical models

A.4.1. *t*-test

In the following paragraphs, I want to give some examples on how to report a statistical model. Let's start with a simple one, an independent two sample *t*-test:

$$t = \frac{m_A - m_B}{\sqrt{\frac{s^2}{n_A} + \frac{s^2}{n_B}}} \quad (\text{A.1})$$

where s^2 is an estimator of the common variance of the two samples. It can be calculated as

$$s^2 = \frac{\sum (x - m_A)^2 + \sum (x - m_B)^2}{n_A + n_B - 2} \quad (\text{A.2})$$

Once the *t*-test statistic value is calculated, one uses the critical value of Student's *t*-distribution corresponding to the significance level alpha of your choice (5%). The degrees of freedom (*df*) used in this test are $df = n_A + n_B - 2$. We can simulate some data according to equation (A.1) and apply the function `t.test()` from the `stats` package:

```
N <- 100
delta <- 5
same_sd <- 5
df_ttest <- tibble(class = gl(n = 2, k = N/2, labels = c("Class A", "Class B")),
                    exam_score = c(rnorm(N/2, mean = 50, sd = same_sd),
                                   rnorm(N/2, mean = 50 + delta, sd = same_sd)))
test1 <- t.test(exam_score ~ class, data = df_ttest, var.equal = TRUE)
test1_glance <- glance(test1)
test1

#>
#> Two Sample t-test
#>
#> data: exam_score by class
#> t = -4.0128, df = 98, p-value = 0.0001174
#> alternative hypothesis: true difference in means between group Class A and group Class B is
#> 95 percent confidence interval:
#> -6.470517 -2.188397
#> sample estimates:
#> mean in group Class A mean in group Class B
#> 49.94616 54.27562
```


This console output is not very pleasant and should not be reported as this. Better to use the package `broom` and its function `broom::glance()` to extract everything you need using inline code chunks, which gives you a significant difference of ≈ -4.33 between class A ($M = 49.95$, $SD = 4.65$) and class B ($M = 54.28$, $SD = 6.05$) in this case, $t(98) = -4.013$, $p < .001$. You should read the source code of this paragraph carefully to see how everything in the inline chunks fits together to produce such an output.

A.4.2. χ^2 -test

The same procedure can be used to report a χ^2 -test using the function `chisq.test()` from the `stats` package. This time, let's use the `mpg` data set imported above in section A.2:

```
# Build a contingency table for year and cylinders
tbl_df <- table(df1$year, df1$cyl)
chi_test <- chisq.test(tbl_df)
chi_result <- glance(chi_test)
tbl_df
```

```
#>
#>      4 Cylinders 5 Cylinders 6 Cylinders 8 Cylinders
#> 1999          45           0           45          27
#> 2008          36           4           34          43
```

```
chi_test
```

```
#>
#> Pearson's Chi-squared test
#>
#> data:  tbl_df
#> X-squared = 10.189, df = 3, p-value = 0.01703
```

```
chi_result
```

```
#> # A tibble: 1 x 4
#>   statistic p.value parameter method
#>   <dbl>    <dbl>     <int> <chr>
#> 1      10.2  0.0170         3 Pearson's Chi-squared test
```

In this toy example, we can report that the cell means appear to be significantly different from each other, in other words, that they are not independent, $\chi^2(3) = 10.189$, $p = 0.017$.

Because it is very tedious to use the `ifelse()` command inside an inline code chunk to print the p -value correctly, one can define a function for printing the p -value that simplifies the source code a little bit like in the following code chunk.

```
print_p_value <- function(p.num, DIGITS = 3) {  
  if (abs(p.num) < 0.001) {  
    number <- '<~.001'  
  } else if (abs(p.num) > 0.9) {  
    number <- '>~.9'  
  } else {  
    number <- paste0('=~',  
                     stringr::str_replace(round(p.num, dig = DIGITS),  
                                           '0\\.\\.', '\\.'))  
  }  
  return(as.character(number))  
}
```

This gives you the possibility to write the test as follows, $\chi^2(3) = 10.189$, $p = .017$. Please look at the source code where the χ^2 -test is reported for the second time to see the difference to the inline code chunk from before.

A.4.3. Linear regression models

In this section, we will again use the data set loaded in section A.2, where we formulate different linear regression models using the function `lm()` from the `stats` package to predict the outcome `hwy` (highway miles per gallon). The first one will be a more complicated model including a continuous predictor, `displ` (displacement), two categorical predictors, `year` and `cyl` (number of cylinders), and the interaction between the two categorical independent variables. The second one will be a model with all three predictors but without the interaction, and the third one will also omit the continuous predictor variable. Because there are only some cars with five cylinders, these observations are excluded beforehand to simplify the models. After fitting the three models that are all nested (the second is a simpler version of the first, the third a simpler version of the second model), all three models are compared using the `anova()` function from the `stat` package, see table A.4, which is produced using the `broom` package and some `tidyverse` and `kableExtra` magic (again).

```

df1_small <- df1 %>% filter(cyl != "5 Cylinders") %>%
  mutate(cyl = droplevels(cyl))

m1 <- lm(hwy ~ year + cyl + displ + year:cyl,
        data = df1_small,
        contrasts = list(year = "contr.treatment",
                        cyl = "contr.treatment"))
m2 <- update(m1, . ~ . - year:cyl)
m3 <- update(m2, . ~ . - displ)

tidy(anova(m1, m2, m3)) %>%
  mutate(across(where(is.numeric), ~ as.character(round(.x, digits = 3)))) %>%
  mutate(across(where(is.character), ~ if_else(is.na(.x), "", .x))) %>%
  rename("Residual $df$" = `df.residual`,
        "RSS" = rss,
        "$df$" = df,
        "Sum of Squares" = sumsq,
        "Statistic" = statistic,
        "$p$-value" = p.value) %>%
  mutate(Model = c(formula(m1)[[3]], formula(m2)[[3]], formula(m3)[[3]])) %>%
  select(Model, everything(), -term) %>%
  kbl(caption = "Analysis of variance table for three linear models",
      booktabs = TRUE, escape = FALSE, align = "lccrrr",
      centering = TRUE) %>%
  kable_styling(latex_options = c("striped", "HOLD_position",
                                "scale_down")) %>%
  add_footnote(label = paste0("cyl = cylinder; ",
                              "displ = displacement; ",
                              "$df$ = degrees of freedom; ",
                              "RSS = Residual Sum of Squares"),
              notation = "none", escape = FALSE)

```

Table A.4.: Analysis of variance table for three linear models

Model	Residual <i>df</i>	RSS	<i>df</i>	Sum of Squares	Statistic	<i>p</i> -value
year + cyl + displ + year:cyl	223	3117.436				
year + cyl + displ	225	3122.895	-2	-5.459	0.195	0.823
year + cyl	226	3364.355	-1	-241.46	17.272	0

cyl = cylinder; displ = displacement; *df* = degrees of freedom; RSS = Residual Sum of Squares

If you want to know more about the underlying logic behind the statistical part, for example the meaning of analysis of variance in this situation, or what the change of the contrasts here is supposed to do, or what the heck contrasts are to begin with, I can only recommend reading! A good starting point would be the chapter about linear models from the manual *An Introduction into R* (Venables,

Smith, and the R Core Team 2022), the book *An R Companion to Applied Regression* by Fox and Weisberg (2019), or the book *Regression Modeling Strategies* by Harrell, Jr. (2019). There are a lot of books about linear models out there and many of them are dealing with them using R, so it's up to you. If you want to know what the above code does, read it carefully and omit steps to see what element does what!

From the output of table A.4 we can see that in this toy data set case, the smallest model seems to be significantly better fitting the data than the intermediate model with one more predictor, and that there is no significant difference between the second and the most complicated model including the interaction. That means, model three would be better than the others.

But, let's use different packages to produce a side by side table for all three models. The first example, see table A.5, is produced using the `modelsummary` package:

```
modelsummary(
  list("Model 1" = m1, "Model 2" = m2, "Model 3" = m3),
  output = "kableExtra", fmt = 2, booktabs = TRUE,
  escape = FALSE, statistic = NULL, stars = TRUE,
  estimate = "{estimate} ({std.error}){stars}",
  coef_map = c(
    "(Intercept)" = "Constant",
    "year2008" = "Year = 2008",
    "cyl6 Cylinders" = "6 Cylinders",
    "cyl8 Cylinders" = "8 Cylinders",
    "displ" = "Displacement",
    "year2008:cyl6 Cylinders" = "2008  $\times$  6 Cylinders",
    "year2008:cyl8 Cylinders" = "2008  $\times$  8 Cylinders"
  ),
  gof_map = tribble(
    ~raw, ~clean, ~fmt,
    "nobs", "\\# Observations", 0,
    "adj.r.squared", "$adj.~R^2$", 2,
    "aic", "$AIC$", 2,
    "rmse", "$RMSE$", 2,
    "F", "$F$", 2
  ),
  notes = paste0("{\\\\small \\\\textsl{Notes:}~",
    "$+~p~\\\\leq~.1$; ",
    "$*~p~\\\\leq~.05$; ",
    "$**~p~\\\\leq~.01$; ",
    "$***~p~\\\\leq~.001$}"),
  title = "Comparison of three linear models using modelsummary" %>%
  kable_styling(latex_options = c("striped", "HOLD_position"))
```

Table A.5.: Comparison of three linear models using modelsummary

	Model 1	Model 2	Model 3
Constant	33.11 (1.26)***	33.03 (1.22)***	28.34 (0.49)***
Year = 2008	1.21 (0.84)	1.22 (0.50)*	1.04 (0.52)*
6 Cylinders	−3.28 (1.03)**	−3.15 (0.90)***	−5.97 (0.61)***
8 Cylinders	−4.39 (1.89)*	−4.74 (1.70)**	−11.35 (0.64)***
Displacement	−2.26 (0.54)***	−2.22 (0.53)***	
2008 × 6 Cylinders	0.39 (1.19)		
2008 × 8 Cylinders	−0.40 (1.25)		
# Observations	230	230	230
adj. R ²	0.61	0.61	0.58
AIC	1268.25	1264.65	1279.78
RMSE	3.68	3.68	3.82

Notes: + $p \leq .1$; * $p \leq .05$; ** $p \leq .01$; *** $p \leq .001$

Another variant would be to use the `stargazer` package, but here one has to apply several small extra steps to make this work in the bookdown environment we are working in. Firstly, you need to set the code chunk option `results = "asis"`, then you must set the `label` option in the `stargazer` function to the exact label you want to cross-reference to, including the “tab:” part, e.g., `label = "tab:m123-stargazer"`, and lastly you must specify the argument `header = FALSE` in the `stargazer` function call to suppress the message “Table built by...”. Everything else is a question of using the correct options to tweak the output in the direction you want. `Stargazer` does have sensible defaults and useful settings, but one drawback is that it cannot be adjusted using `kableExtra` at the end. Have a look at the result in table A.6 and compare this to the corresponding source code to see how it works.

```
stargazer(m1, m2, m3,
  title = "Comparison of three linear models using stargazer",
  label = "tab:m123-stargazer",
  covariate.labels = c("Constant",
    "Year = 2008",
    "6 Cylinders",
    "8 Cylinders",
    "Displacement",
    "2008  $\times$  6 Cylinders",
    "2008  $\times$  8 Cylinders"),
  ci = TRUE, ci.level = 0.95, header = FALSE, digits = 2,
  intercept.bottom = FALSE, intercept.top = TRUE,
  table.placement = "H", font.size = "small")
```

Table A.6.: Comparison of three linear models using stargazer

	<i>Dependent variable:</i>		
	hwy		
	(1)	(2)	(3)
Constant	33.11*** (30.65, 35.58)	33.03*** (30.64, 35.42)	28.34*** (27.39, 29.29)
Year = 2008	1.21 (−0.43, 2.85)	1.22** (0.24, 2.20)	1.04** (0.03, 2.05)
6 Cylinders	−3.28*** (−5.30, −1.26)	−3.15*** (−4.91, −1.40)	−5.97*** (−7.16, −4.77)
8 Cylinders	−4.39** (−8.09, −0.68)	−4.74*** (−8.07, −1.41)	−11.35*** (−12.60, −10.10)
Displacement	−2.26*** (−3.31, −1.20)	−2.22*** (−3.27, −1.18)	
2008 × 6 Cylinders	0.39 (−1.95, 2.72)		
2008 × 8 Cylinders	−0.40 (−2.84, 2.04)		
Observations	230	230	230
R ²	0.62	0.62	0.59
Adjusted R ²	0.61	0.61	0.58
Residual Std. Error	3.74 (df = 223)	3.73 (df = 225)	3.86 (df = 226)
F Statistic	59.95*** (df = 6; 223)	90.48*** (df = 4; 225)	107.07*** (df = 3; 226)

Note:

*p<0.1; **p<0.05; ***p<0.01

If you want to produce an inline result from a specific model you can do this as before by hand, or you can use the package `gtsummary`, which gives you the possibility of directly reporting statistical results using inline functions like `tbl_summary()` and `inline_text()`. As an example, the coefficient for six cylinders in model 3 is -6.0 (0.95% *CI* $-7.2, -4.8$; $p < 0.001$). Have a look in the source code to see how this is accomplished, but be aware that the argument pattern within the function call to `inline_text()` must be provided in this case because we want to render a PDF-file and `gtsummary` is currently mainly aiming at HTML-output. The difference between the numbers in the inline output and table A.6 are due to rounding. If you want to look into the given capabilities of `gtsummary` regarding inline reporting, check out this [presentation](#) and the [package documentation](#).

A.4.4. Generalized linear regression models

Generalized linear models (GLMs), first introduced in this comprehensive manner by Nelder and Wedderburn (1972) are models in which the outcome does not need to belong to a normal distribution, but where the simple linear model is just a special case. For example, the outcome can belong to a *Poisson* or a *negative – binomial* distribution (for count data, i.e., only integer values and no value less than zero), to a *Gamma* distribution (for only positive decimal values, not only integers), to a *binomial* distribution (for the number of success in a fixed set of trials), or to a *bernoulli* distribution, which is a simple case of the *binomial* distribution, where the outcome can only be either one or zero (i.e., yes/no, true/false). There are a lot of possible ways and also user provided packages which make it feasible to model such outcomes using the most appropriate distribution for the data at hand, but the starting point is mainly the function `glm()` from the stats package.

This document can not introduce you to the statistical concepts behind GLMs in general, but I want to give one example of logistic regression to demonstrate the general workflow and to give examples of plotting marginal means. For this purpose, I will use the famous titanic data set (Dawson 1995), which was further greatly updated and improved by Thomas Cason using the Encyclopedia Titanica to create a new dataset called `titanic3`, which can be obtained [here](#) and which can also be obtained through the `Hmisc` package (Harrell Jr 2022).

```
titanic <- read_csv("02-data/titanic3.csv",
  col_types = cols(
    pclass = col_double(),
    survived = col_double(),
    name = col_character(),
    sex = col_character(),
    age = col_double(),
    sibsp = col_double(),
    parch = col_double(),
    ticket = col_character(),
    fare = col_double(),
    cabin = col_character(),
    embarked = col_character(),
    boat = col_character(),
    body = col_double(),
    home.dest = col_character()
  ), lazy = FALSE)
titanic$pclass <- factor(titanic$pclass,
  levels = c(1,2,3),
  labels = c("1st", "2nd", "3rd"))
```

The original (non-enhanced) dataset based on data originally collected by the British Board of Trade also comes with the `datasets` package in R, but provides only the variables `class`, `sex`, `age`, and `survived` for each person on board of the Titanic. The enhanced version additionally includes variables like `age`, the ticket fare, the cabin or the place where the person embarked and some others. Next to that, the variable `age` is changed from a categorical one (child vs. adult) to the actual numeric age in years. The data set comprises 1309 observations.

In the next step, we want to predict if someone survived the Titanic based on the variables `pclass`, `sex` and `age` and the interaction between `sex` and `age`. The dependent variable is `survived`, encoded as 0 or 1, which means the model predicts the mean probability of surviving the Titanic.

```
mlog1 <- glm(survived ~ pclass + sex + age + sex:age,
              data = titanic, family = binomial)
summary(mlog1)
```

```
#>
#> Call:
#> glm(formula = survived ~ pclass + sex + age + sex:age, family = binomial,
#>      data = titanic)
#>
#> Deviance Residuals:
#>      Min       1Q   Median       3Q      Max
#> -2.3844  -0.6721  -0.4063   0.7041   2.5440
#>
#> Coefficients:
#>              Estimate Std. Error z value Pr(>|z|)
#> (Intercept)  2.790834    0.362823   7.692 1.45e-14 ***
#> pclass2nd   -1.424583    0.241513  -5.899 3.67e-09 ***
#> pclass3rd   -2.388177    0.236380 -10.103 < 2e-16 ***
#> sexmale     -1.029755    0.358593  -2.872  0.00408 **
#> age         -0.004084    0.009461  -0.432  0.66600
#> sexmale:age -0.052891    0.012025  -4.398 1.09e-05 ***
#> ---
#> Signif. codes:
#> 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
#>
#> (Dispersion parameter for binomial family taken to be 1)
#>
#>      Null deviance: 1414.62  on 1045  degrees of freedom
#> Residual deviance:  961.92  on 1040  degrees of freedom
#> (263 Beobachtungen als fehlend gelöscht)
#> AIC: 973.92
#>
#> Number of Fisher Scoring iterations: 5
```


Again, the default console output is not feasible for a written report, but is printed here to explain some points about the model. The estimated numbers here are on the scale of the linear predictor, that is, they cannot be interpreted as probability values, which is why you see negative numbers. In logistic regression, a linear combination of covariate values (which can take values between $\pm\infty$) is converted to the scale of a probability (between 0 and 1) using the logit link function, which is the inverse of the standard logistic function $\sigma(x) = 1/(1 + e^{-x})$, with its definition stated in see equation (A.3).

$$\text{logit}(\theta_i) = \ln\left(\frac{\theta_i}{1 - \theta_i}\right) = \beta_0 + \beta_1 \times x_1 + \dots + \beta_p \times x_p \quad (\text{A.3})$$

That means that after exponentiating both sides we have the odds, see equation (A.4), which are easier to interpret.

$$\text{odds} = \theta_i = \frac{\theta_i}{1 - \theta_i} = e^{\beta_0 + \beta_1 \times x_1 + \dots + \beta_p \times x_p} \quad (\text{A.4})$$

In a logistic regression, the response being modeled is the $\log(\text{odds})$ that $Y = 1$. Therefore, the regression coefficients give the change in $\log(\text{odds})$ in the response for a unit change in the predictor variable, holding all other predictor variables constant. The odds ratio can then be defined as in equation (A.5).

$$OR = \frac{\text{odds}(x + 1)}{\text{odds}(x)} = \frac{e^{\beta_0 + \beta_1(x+1)}}{e^{\beta_0 + \beta_1 x}} = e^{\beta_1} \quad (\text{A.5})$$

This exponential relationship, see equation (A.5), provides an interpretation for β_1 : The odds multiply by e^{β_1} for every 1-unit increase in x . So, if we take the coefficient for being male in the above model (-1.0297546) and take the exponential of it (≈ 0.3570946), we can say that a male passenger has a chance of surviving when compared to a female passenger which is reduced by a factor of 0.3570946. That roughly means that a male passenger only has a 64% lower chance of survival than a female passenger. The probability value for the female passenger is not directly obvious from the above model output, because it serves as a baseline category in this model and is not explicitly named in the above output but is indicated by the intercept.

Using package `jtools` (which utilizes package `huxtable` for table formatting), one can get another decent model summary table (see table A.7), but you can as well use the aforementioned packages like `modelsummary` or `stargazer`.

```
export_summs(mlog1, digits = 2, error_pos = "right", exp = TRUE,
  error_format = "[{conf.low}, {conf.high}]",
  model.names = "Dependent variable: Survived",
  coefs = c("Intercept" = "(Intercept)",
    "2nd Passenger Class" = "pclass2nd",
    "3rd Passenger Class" = "pclass3rd",
    "Male Passenger" = "sexmale",
    "Age" = "age",
    "Male Passenger x Age" = "sexmale:age")) %>%
  huxtable::set_caption('A logistic regression model for the titanic data set using packa
```

Table A.7.: A logistic regression model for the titanic data set using package `jtools`

	Dependent variable: Survived	
Intercept	16.29 ***	[8.00, 33.18]
2nd Passenger Class	0.24 ***	[0.15, 0.39]
3rd Passenger Class	0.09 ***	[0.06, 0.15]
Male Passenger	0.36 **	[0.18, 0.72]
Age	1.00	[0.98, 1.01]
Male Passenger x Age	0.95 ***	[0.93, 0.97]
N	1046	
AIC	973.92	
BIC	1003.63	
Pseudo R2	0.47	

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Another way to produce such a model table is using package `gtsummary` in conjunction with `kableExtra`, see table A.8. The only problem here is that you have to “rewrite” the column names because on the way from `gtsummary` output to `kableExtra`, the superscripts are lost which renders the footnote a little bit without meaning.

```
tbl_regression(mlog1, exponentiate = TRUE,
               pvalue_fun = ~style_pvalue(.x, digits = 2),
               label = list(pclass ~ "Passenger Class",
                           sex ~ "Sex",
                           age ~ "Age"
                           )) %>%
  add_global_p() %>% # add global p-value
  add_nevent() %>% # add number of events of the outcome
  add_q() %>% # adjusts global p-values for multiple testing
  bold_p() %>% # bold p-values under a given threshold (default 0.05)
  bold_p(t = 0.05, q = TRUE) %>% # bold q-values under the threshold of 0.05
  bold_labels() %>%
  italicize_levels() %>%
  as_kable_extra(format = "latex", booktabs = TRUE,
                 linesep = "", escape = FALSE,
                 caption = 'A logistic regression model for the titanic data set using package gtsummary',
                 col.names = c("Coefficient", "$\\mathrm{Event}\\sim N$", "$OR^{1}$",
                              "$95\\sim\\mathrm{CI}^{1}$",
                              "$p-\\mathrm{value}$",
                              "$q-\\mathrm{value}^{2}$")) %>%
  kable_styling(latex_options = c("striped", "HOLD_position"))
```

Table A.8.: A logistic regression model for the titanic data set using package gtsummary

Coefficient	Event N	OR^1	95 CI^1	p – value	q – value ²
Passenger Class	427			<0.001	<0.001
1st		—	—		
2nd		0.24	0.15, 0.38		
3rd		0.09	0.06, 0.14		
Sex	427			0.004	0.005
female		—	—		
male		0.36	0.18, 0.72		
Age	427	1.00	0.98, 1.01	0.67	0.67
Sex * Age	427			<0.001	<0.001
male * Age		0.95	0.93, 0.97		

¹ OR = Odds Ratio, CI = Confidence Interval² False discovery rate correction for multiple testing

As you have seen, there are a lot of possibilities to generate model and summary tables. It depends on what you need to do, what amount of time you are willing to invest into getting what you want and how satisfied you are with the output generated by one of these helper packages. There are lots of possibilities to tweak the output in more than one way and I would guess that in 90% of the cases, a pre-generated model table is doing the job just great. But, in case it does not, you can always

resort to writing down a custom \LaTeX table on your own and fill in the cells with inline R chunks that give you exactly the number you want. In this way you can completely decide how your table should look like.

A.4.5. Automated report generation

Another automated way to report a model is using the report package (Makowski et al. 2021), for example:

```
report(mlog1)
```

We fitted a logistic model (estimated using ML) to predict survived with pclass (formula: `survived ~ pclass + sex + age + sex:age`). The model's explanatory power is substantial (Tjur's $R^2 = 0.39$). The model's intercept, corresponding to `pclass = 1st`, is at 2.79 (95% CI [2.09, 3.51], $p < .001$). Within this model:

- The effect of `pclass [2nd]` is statistically significant and negative (beta = -1.42, 95% CI [-1.91, -0.96], $p < .001$; Std. beta = -1.42, 95% CI [-1.91, -0.96])
- The effect of `pclass [3rd]` is statistically significant and negative (beta = -2.39, 95% CI [-2.86, -1.93], $p < .001$; Std. beta = -2.39, 95% CI [-2.86, -1.93])
- The effect of `sex [male]` is statistically significant and negative (beta = -1.03, 95% CI [-1.74, -0.33], $p = 0.004$; Std. beta = -2.61, 95% CI [-2.96, -2.28])
- The effect of `age` is statistically non-significant and negative (beta = -4.08e-03, 95% CI [-0.02, 0.01], $p = 0.666$; Std. beta = -0.06, 95% CI [-0.32, 0.21])
- The interaction effect of `age on sex [male]` is statistically significant and negative (beta = -0.05, 95% CI [-0.08, -0.03], $p < .001$; Std. beta = -0.76, 95% CI [-1.11, -0.43])

Standardized parameters were obtained by fitting the model on a standardized version of the dataset. 95% Confidence Intervals (CIs) and p-values were computed using a Wald z-distribution approximation. We fitted a logistic model (estimated using ML) to predict survived with sex (formula: `survived ~ pclass + sex + age + sex:age`). The model's explanatory power is substantial (Tjur's $R^2 = 0.39$). The model's intercept, corresponding to `sex = female`, is at 2.79 (95% CI [2.09, 3.51], $p < .001$). Within this model:

- The effect of pclass [2nd] is statistically significant and negative (beta = -1.42, 95% CI [-1.91, -0.96], $p < .001$; Std. beta = -1.42, 95% CI [-1.91, -0.96])
- The effect of pclass [3rd] is statistically significant and negative (beta = -2.39, 95% CI [-2.86, -1.93], $p < .001$; Std. beta = -2.39, 95% CI [-2.86, -1.93])
- The effect of sex [male] is statistically significant and negative (beta = -1.03, 95% CI [-1.74, -0.33], $p = 0.004$; Std. beta = -2.61, 95% CI [-2.96, -2.28])
- The effect of age is statistically non-significant and negative (beta = -4.08e-03, 95% CI [-0.02, 0.01], $p = 0.666$; Std. beta = -0.06, 95% CI [-0.32, 0.21])
- The interaction effect of age on sex [male] is statistically significant and negative (beta = -0.05, 95% CI [-0.08, -0.03], $p < .001$; Std. beta = -0.76, 95% CI [-1.11, -0.43])

Standardized parameters were obtained by fitting the model on a standardized version of the dataset. 95% Confidence Intervals (CIs) and p-values were computed using a Wald z-distribution approximation. and We fitted a logistic model (estimated using ML) to predict survived with age (formula: `survived ~ pclass + sex + age + sex:age`). The model's explanatory power is substantial (Tjur's $R^2 = 0.39$). The model's intercept, corresponding to age = 0, is at 2.79 (95% CI [2.09, 3.51], $p < .001$). Within this model:

- The effect of pclass [2nd] is statistically significant and negative (beta = -1.42, 95% CI [-1.91, -0.96], $p < .001$; Std. beta = -1.42, 95% CI [-1.91, -0.96])
- The effect of pclass [3rd] is statistically significant and negative (beta = -2.39, 95% CI [-2.86, -1.93], $p < .001$; Std. beta = -2.39, 95% CI [-2.86, -1.93])
- The effect of sex [male] is statistically significant and negative (beta = -1.03, 95% CI [-1.74, -0.33], $p = 0.004$; Std. beta = -2.61, 95% CI [-2.96, -2.28])
- The effect of age is statistically non-significant and negative (beta = -4.08e-03, 95% CI [-0.02, 0.01], $p = 0.666$; Std. beta = -0.06, 95% CI [-0.32, 0.21])
- The interaction effect of age on sex [male] is statistically significant and negative (beta = -0.05, 95% CI [-0.08, -0.03], $p < .001$; Std. beta = -0.76, 95% CI [-1.11, -0.43])

Standardized parameters were obtained by fitting the model on a standardized version of the dataset. 95% Confidence Intervals (CIs) and p-values were computed using a Wald z-distribution approximation.

All the text since the last code chunk was automatically generated by this one function call. have a look at the chunk options to see how this is printed as normal text and not as console output.

A.5. Plotting statistical models

To really understand what a regression model is telling you, you should not just stare at a summary table but you should plot the predictions of a model. There, you can see how the dependent variable is changing when a predictor variable is changing, normally while holding all other predictors constant (e.g., at 0 or the sample mean). That means that you need to calculate the predicted values from the model given different input values for the predictors, calculate the lower and upper confidence intervals according to some level of confidence (normally 95%) and plot all these together. In the case of a GLM one should decide if these numbers should be transformed from the scale of the linear predictor to the scale of the response, for example in case of a logistic regression model, if you should plot the probability instead of the log odds.

There are several packages available that make this task easier. Some of them are `effects` Fox and Weisberg (2019), `ggeffects` (Lüdtke 2018), `jtools` (Long 2022), see (Lüdtke et al. 2021) or `emmeans` (for estimated marginal means, Lenth 2022).

A first example using `ggeffects`:

```
eff1 <- ggpredict(mlog1, terms = "pclass")
plot(eff1) + labs(x = "Passenger Class", y = "Probability of Survival",
                 title = element_blank()) +
  scale_y_continuous(labels = scales::percent, limits = c(0, 0.65))
```

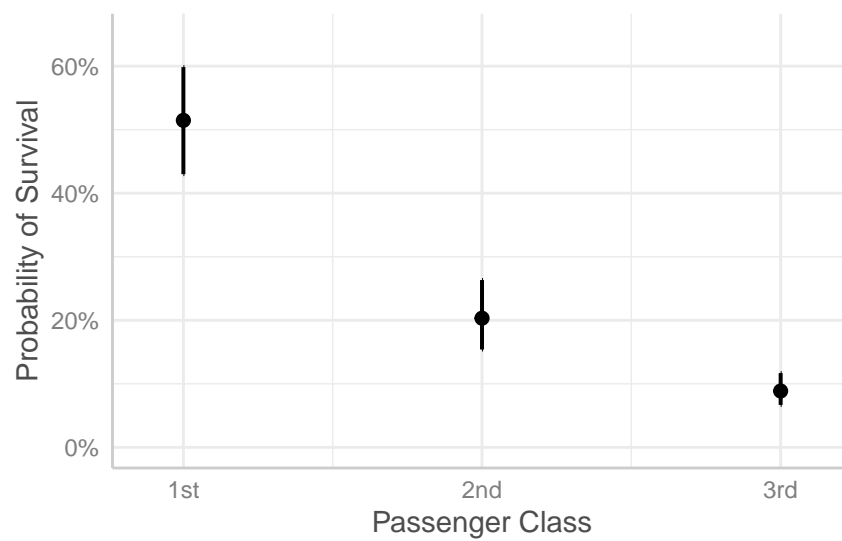


Figure A.1.: Predicted probabilities of survival for each passenger class

Here, you can see another example to visualize the interaction between sex and age, that is, an interaction between a continuous and a categorical predictor.

```
eff2 <- ggpredict(mlog1, terms = c("age [all]", "sex"))
plot(eff2) + labs(x = "Age", y = "Probability of Survival",
                 title = element_blank()) +
  theme(legend.position = "bottom") +
  guides(color = guide_legend(title = "Sex"))
```

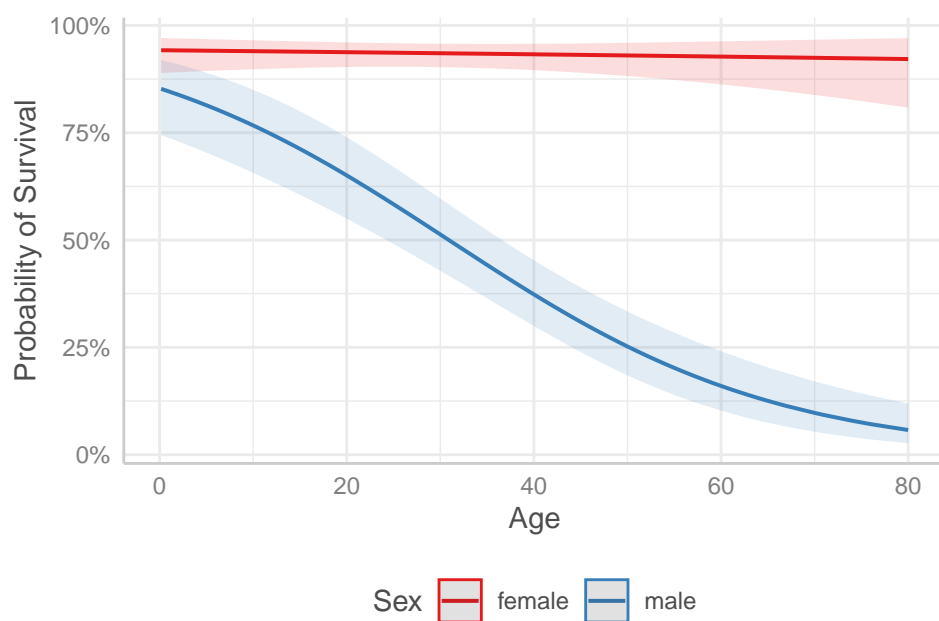


Figure A.2.: Predicted probabilities of survival depend on sex and age

Coming back to the multiple regression model from above (see section A.4.3), especially model 1 (see table A.5), we can generate one visualization for all the main effects and one for the interaction. In a “real” scientific work you would not present the main effects for themselves in presence of an interaction involving these main effects, but for demonstration purposes, we want to generate four visualizations and put them together in one plot using the package `patchwork` (Pedersen 2022). The code for this is placed on the following page, and the figure it produces comes on the next one. By the way, have a look into the chunk options for the last chunk, where both the arguments `fig.cap` and `fig.scap` are used to produce a caption and a short caption for figure A.3, where the former is printed under the figure itself and the latter is used in the list of figures to have a smaller output in the frontmatter.


```
m1_year <- ggpredict(m1, terms = "year")
m1_cyl <- ggpredict(m1, terms = "cyl")
m1_displ <- ggpredict(m1, terms = "displ [all]")
m1_year_cyl <- ggpredict(m1, terms = c("cyl", "year"))

m1_year_plot <- plot(m1_year) + labs(x = "Year",
  y = "Highway Miles per Gallon", title = element_blank()) +
  scale_y_continuous(limits = c(0, NA),
    breaks = seq(from = 0, to = 50, by = 5))
m1_cyl_plot <- plot(m1_cyl) + labs(x = "",
  y = "Highway Miles per Gallon", title = element_blank()) +
  scale_y_continuous(limits = c(0, NA),
    breaks = seq(from = 0, to = 50, by = 5))
m1_displ_plot <- plot(m1_displ) + labs(x = "Displacement",
  y = "Highway Miles per Gallon", title = element_blank()) +
  scale_y_continuous(limits = c(0, NA),
    breaks = seq(from = 0, to = 50, by = 5))
m1_year_cyl_plot <- plot(m1_year_cyl) + labs(x = "",
  y = "Highway Miles per Gallon", title = element_blank()) +
  guides(color = guide_legend(title = "Year")) +
  scale_y_continuous(limits = c(0, NA),
    breaks = seq(from = 0, to = 50, by = 5))

m1_year_plot + m1_cyl_plot + m1_displ_plot + m1_year_cyl_plot +
  plot_annotation(tag_levels = 'A') +
  plot_layout(guides = 'collect') &
  theme(legend.position = 'bottom')
```

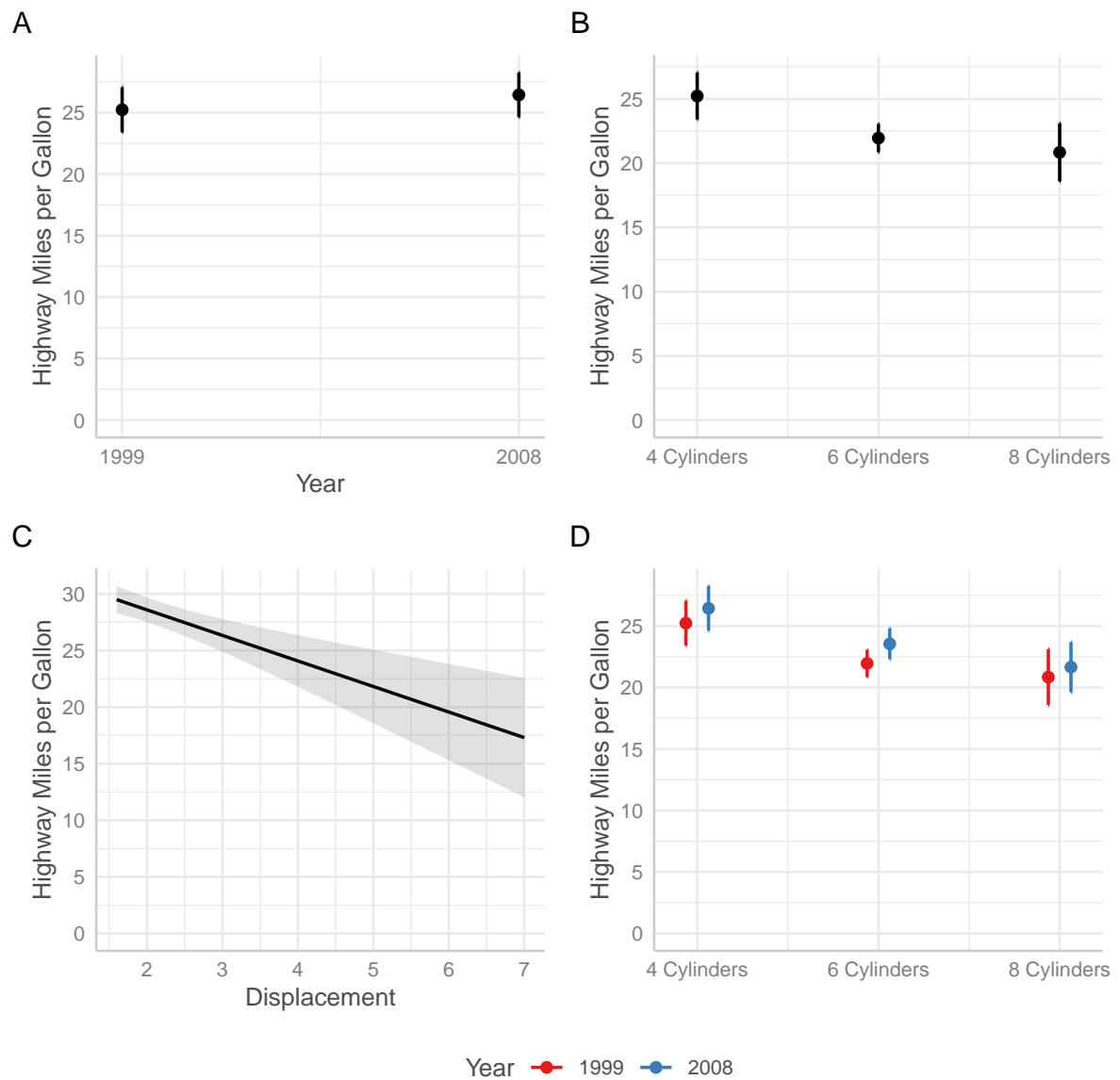


Figure A.3.: One overall plot with four subplots: (A) predictor Year, (B) predictor Cylinders, (C) predictor Displacement, and (D) the interaction between Year \times Cylinders

This is the end! Good luck with writing your own report or thesis using this template!

B. Data-set

```
library(tidyverse) # This includes readr!
library(xtable) # For displaying LaTeX tables
library(modelsummary) # For displaying regression models in tables
library(stargazer) # For displaying regression models in tables
library(jtools) # For displaying regression models in tables
library(kableExtra) # For displaying or changing tables
library(gt) # For displaying tables
library(gtsummary) # For model reporting inline and in tables
library(broom) # For working with statistical models
library(car) # For type-III anova tests
library(report) # For automated text-based model reporting
library(effects) # For working with statistical models / visualize effects
library(ggeffects) # For working with statistical models / visualize effects
library(patchwork) # For putting different visualizations in one figure

dataset <- read_csv("02-data/cost-of-living-2017.csv", lazy= FALSE)
```

```
#> Rows: 511 Columns: 1
#> -- Column specification -----
#> Delimiter: ","
#> chr (1): City      State   Country Cost of Living Plus Rent Ind...
#>
#> i Use `spec()` to retrieve the full column specification for this data.
#> i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```