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The Impact of Global Environmental Governance Signalling on Firm Innovation; Revisiting the Porter Hypothesis at the International Level.

THESIS

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by

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RESUME / ABSTRACT

This *RMarkdown* template is for writing a Graduate Institute thesis.
This template's sample content include illustrations of how to write a thesis in *RMarkdown*, and largely follows the structure from this R Markdown workshop.
Congratulations for taking a step further into the lands of open, reproducible science by writing your thesis using a tool that allows you to transparently include tables and dynamically generated plots directly from the underlying data. Hip hooray!

Acknowledgements

I would like to express my heartfelt thanks to Prof. Joëlle Noailly for her supervision without which the present work would not exist. Her guidance on how to adress methodological issues as well as her insight in the field of environmental economics proved to be invaluable in the writing of this thesis. Additionally, I would like to thank Prof. James Hollway for the co-supervision of this thesis and in particular for the collaboration within the PANARCHIC project which allowed me to continuously refine my programming skills and discover the importance of social network analysis to further refine our understanding of social issues. Furthermore, I would like to thank Henrique Sposito, Jael Tan and Esther Peev, all members of the PANARCHIC team, for their help.

Bernhard Bieri
Geneva Graduate Institute
30 June 2022

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Introduction

Chapter 2

Litterature Review

The present paper draws from three distinct but complementary strands of the literature on environmental policy. First and foremost, we ought to characterize what is known in the literature as the *Porter Hypothesis* and distinguish the different versions that have been devised over the years. We will thus strive to understand the impact of increased environmental regulations on both innovative activity of firms and on overall firm performance before completing the analysis by highlighting works that looked at the impact of the nature of environmental policy on firm-level innovation. The next strand of the literature relates to the concept of *policy certainty* which highlights the importance of designing policies that Finally, and most central to our contribution, lies the literature on *International Environmental Governance* and the related methodological advances to understand it within a network framework.

2.1 The Porter Hypothesis

Over three decades ago, the Porter Hypothesis (PH) challenged the conventional Panglossian economic thinking that enhanced environmental regulation would lead to a decrease in economic performance of firms due to the increased constraints imposed on the firm (Porter 1991). The main intuition behind the Panglossian doxa is that if it were profitable for firms to follow a more sustainable production path, they would do so in the absence of regulations. On the basis of case studies, Porter however argues that well designed, market-based, pollution preventing policies would lead firms to create products that are more resource efficient and thus competitive on the international market. An example of the latter could be the implementation of more stringent fuel consumption standards for cars. Porter thus advances that this increase in environmental stringency, would force domestic automobile companies to make more fuel efficient cars which in turn would increase the competitiveness of domestic cars in the world market.

Porter and Von der Linde later formalize his initial criticism in Porter and van der Linde (1995) where they outline six main causal links between increased environmental regulations and innovation or firm performance. First, they contend that "regulation signals companies about likely resource inefficiencies and potential technological improvements. Second, they argue that"regulation focused on information gathering can achieve major benefits [in terms of environmental performance and economic performance] by raising corporate awareness". Third, they mention that "environmental regulation reduces the"uncertainty that investments to address the environment will be valuable". Fourth, they advance that outside pressure, which includes the regulatory framework firms have to comply with, is able to overcome organizational inertia and motivate innovation. The fifth reason put forward by the authors is that "regulation levels the transitional playing field" in the sense that regulation ensures that companies do not gain an unfair advantage until new and improved technologies are proven. The sixth and final argument pertains to an important nuance between the effect of regulation on innovation and competitiveness of firms in that compliance costs arising from environmental regulations might not always be offset by benefits brought by product innovations. Crucially, Porter and Van der Linde contend that most benefits occurring from increased innovation will arise in the medium to the long term due to the required time span for the innovation to bear fruits. Hence the existence of a lag between the implementation of an environmental regulation and a signal on innovation or economic performance metrics of firms is likely.

Due to its unorthodox nature, the Porter Hypothesis generated a strong debate among economists during the late 1990's and the early 2000's (Jaffe, Peterson, et al. 1995). Ambec, Cohen, et al. (2013) provide a clear overview of the various arguments proponents used to defend the *PH*. They define a first set of studies which underlines the fact that firms are driven by individuals who might not satisfy the assumptions of rationality required for firms to be deemed profit-maximizers. Indeed, managerial risk-aversion, resistance to change (Aghion et al. 1997), and a combination of lacking information and the cognitive capabilities to process the latter (Gabel and Sinclair-Desgagné 2001) may cause a mismatch between the utility maximizing behaviors of the management and the firm as a whole. Akin to this principal agent issue, Ambec and Barla (2002) argue that managers may exhibit rent-seeking behavior by retaining private information on the true costs of technological innovations that would improve productivity and the environmental performance of the firm. This essentially follows the organizational inertia and learning effects put forward by Porter and van der Linde (1995) and outlined above.

A second strand of the theoretical literature explore the role of market failures beyond the pure environmental externalities generated by pollution and how increased environmental regulations could overcome them. Examples of this strand include situations where firms are first movers within international markets characterized by imperfect competition where domestic production may increase as a result of more stringent environmental regulation (Simpson and Bradford 1996). Another common market failure that could lead to the coexistence of the *PH* alongside profit-maximizing firms are information asymmetries between households and firms. The main idea here is that by setting industry standards or labels, firms are able to credibly communicate the environmental benefits of their products and overcome the asymmetry (Ambec and Barla 2007). Finally, the non-exclusive nature of R&D may lead to spillovers from the innovating firm to other firms in the industry. This may lead the economy to be in a bad equilibrium where firms invest too little in environmental technologies. If this is indeed the case, then regulations can level the playing field among firms and lead to a move to the higher, more R&D intensive equilibrium (Mohr 2002).

On the empirical front, much has been written to reinforce the initially very theoretical debate surrounding the Porter Hypothesis. To facilitate its analysis, Jaffe and Palmer (1997) divided the original hypothesis into three distinct ones. What is known as the "Strong Porter Hypothesis" (*SPH*) links environmental regulation to firm competitiveness. The "Weak Porter Hypothesis" (*WPH*) links regulation to innovation, and the "Narrow Porter Hypothesis" argues that flexible market-based regulations are more effective in generating innovation than stricter command-and-control policies[1].

The empirical literature analyzing the weak version of the Porter Hypothesis usually operationalizes innovation as R&D expenditures or through (aggregate or sector specific) patent counts. When instead analysing the strong version of the *PH* studies usually rely on firm profits. On the right hand side, the independent variable, environmental policy stringency, was initially proxied

[1]Since we will focus on the former two two hypotheses, we will not elaborate on the "narrow" hypothesis in this literature review.

by pollution abatement costs (Jaffe and Palmer 1997) or energy prices (Newell et al. 1999) before being more holistically estimated via the use of indicators such as the Environmental Policy Stringency (*EPS*) indicator developed by the OECD (Kruse et al. 2022) or national firm-level surveys such as the Community Innovation Survey[2] (Eurostat 2022). As we will outline more in detail in section 3 of the paper, we will take the modern approach and use the EPS index to proxy for environmental regulation stringency at the domestic level and patent counts and business R&D expenditures to proxy inventive activity of firms. The weak version of the Porter Hypothesis is found to be the most consistently verified hypothesis among the three as outlined in the meta-analysis by Cohen and Tubb (2018). The authors of the meta-analysis namely highlight the following points:

- Early studies tend to find a negative relationship between environmental stringency and innovation/competitiveness. More recent studies find a positive relationship between the two variables.
- Cross-country studies are more likely to find a positive link than firm-level studies. One possible reason for this can be found in the fact that innovative activity of upstream equipment manufacturers or new entrants may also respond to changes in the regulatory frameworks within an industry (Noailly and Smeets 2015; Sanyal and Ghosh 2013)[3].
- Studies incorporating a temporal lag between the change in regulation stringency and inventive or profitability outcomes are more likely to find a positive relationship. This echoes once again the original formulation of the Porter Hypothesis which states that while regulation may hurt short term competitiveness and productivity, the long term effects would be positive.

These findings will guide us in the elaboration of a panel model that will be outlined in more detail in section 3. Let us now turn our attention to the second strand of literature use to guide our empirical strategy and examine the impact of policy (un-)certainty on innovation.

[2]See Cohen and Tubb (2018) for a recent meta-analysis of the Porter Hypothesis and an outline of the different measures used.

[3]Furthermore, Cohen and Tubb (2018) note that "[t]o the extent that the Porter Hypothesis as originally formulated focused on the competitiveness of nations, this finding is of particular interest [. . .]". In other words, since the original *PH* focused on nations as the unit of analysis, it is natural to take this unit of analysis when empirically testing it.

2.2 The Role of Policy Certainty on the Innovative Behavior of Firms

While the empirical literature on the impact of policy certainty on innovation is more recent and less abundant than the one investigating the Porter Hypothesis, a number of papers have investigated it. The literature of the impact of policy certainty on innovative activity was derived from the one that links policy uncertainty and investments in tangible assets. Early theoretical contributions outline that non-reversible investments are often delayed or scrapped if firms experience regulatory uncertainty via an increase in the utility derived from the status-quo[4]. On the empirical front, Alesina and Perotti (1996) were the first to investigate this link with a cross-section analysis of over 70 countries. More specifically, they find that more unequal countries are more likely to be politically unstable and political instability in itself has an adverse effect on investments in tangible assets. Additional empirical evidence highlighting the negative effect of policy uncertainty was provided by Bloom, Bond, et al. (2007) who extend the analysis to a panel model, Julio and Yook (2012) who highlight a negative impact of being in an election year on firm investments, and Gulen and Ion (2016) who leverage the Economic Policy Uncertainty index developed by Baker et al. (2016) to describe a similar effect within a panel analysis.

This negative effect between uncertainty and tangible asset investments need not hold for intangible investments in R&D since the latter are different and are namely characterized by a long-term horizon and a fat tailed risk distribution[5]. Bhattacharya et al. (2017) were the first to investigate the effect of policy uncertainty on innovation outcomes (i.e. patent quantities and citations) empirically. They extend the theoretical model proposed by **edmansBlockholderTradingMarket2009** on managerial myopia by adding economic uncertainty, a measure of policy state and a measure of policy uncertainty. Using this theoretical framework, they test whether the pure effect of country level policy orientation as proxied by the Database of Political Institutions and more crucially in our case whether policy uncertainty, as proxied by the occurrence of election events, have an impact on firm-level innovation (**keefer2012database**). Crucially, they are able to show that innovation is more affected by policy uncertainty than by policy itself. This leads to the conclusion that a politically stable environment is beneficial to long-term and high tail risk investments.

[4] See Bernanke (1983) and Bloom, Draca, et al. (2016) for respectively a seminal and a recent theoretical model.
[5] This characteristic is a product of the trial and error nature of the R&D process where only a small subset of research endeavors are successful and profitable.

These studies are looking at the aggregate level effect between policy certainty and innovation. More recently however, newspaper indices on both climate policy uncertainty (Gavriilidis 2021) and on climate policy salience became available (Noailly, Nowzohour, et al. 2021). These indexes are both built by programmatically analyzing US newspaper articles over a given period to detect the co-occurrence of a given set of words[6]. Gavriilidis (2021) used his index to show that increased policy uncertainty lead to a reduction of CO_2 emissions. He further argues that, this might be due to either a decrease in energy consumption and a reduction in non-essential transport or an increase in the demand for renewable energy consumption and an associated increase in climate-friendly innovations. On the other `hand@noailly2021heard` were able to leverage their policy salience index to demonstrate a positive link between policy salience and the probability of cleantech startups receiving venture capital funding. While these indices are able to inform research on the link between environmental policy uncertainty/salience and innovative inputs and outcomes for the US, they cannot yet be used within a panel framework. Furthermore, these indices are symptomatic in that they capture perceptions of an aggregate policy environment. As both papers outline the aggregate sentiment as proxied by newspaper articles, they do not consider the causes of this uncertainty or salience.

This leads us to consider the potential variables which influence domestic environmental policy certainty and may guide innovative activity. Some of these factors have been outlined in the international relations and political science literatures and will be more closely analyzed in the next subsection.

2.3 Global Environmental Governance as a Policy Certainty Signal

Build from Jahn book.

Mention the international environmental governance framework.

[6] Both follow the methodology outlined in the Economic Policy Uncertainty index developed by Baker et al. (2016) and apply different keywords to the programmatic analysis of US newspapers.

Chapter 3

Methods and Data

This section will outline the computation of a novel set of centrality measures which will be used in the subsequent analysis to proxy international environmental policy certainty and

3.1 International Environmental Governance Network:

3.1.1 From a Bipartite Membership Network:

3.1.2 To a Monopartite Cooperation Network:

3.1.3 Selecting and Computing Network Centrality Measures:

3.2 Summary Statistics:

Chapter 4

Results

4.1 An intro to R chunks

One of the most useful parts of *RMarkdown* is the ability to weave or 'knit' text (as we've seen in the previous three chapters) together with the code that produces tables and graphics for your final document. This has various advantages such as:

- *coherence*: for you, having your analysis and text together means keeping a coherent story together about why you did the analysis you did, how you got to your results, and what your interpretation of these results is
- *amendability*: this gives you an opportunity to update the code, for example by filtering the data in a different way, and rerun the code to see how any statistics, tables or graphs related to the data may have changed
- *reproducibility*: this also, importantly, supports a reproducible workflow such that you, or others, can rerun and test the code at a later point

To 'knit' such text and code together, code for particular graphs or tables should first be inserted into the text in 'chunks'. These chunks are opened with three backticks and closed in a new line with another three backticks. The code that produces the desired output is included between these lines, which can include comments etc. A key part of these chunks are the chunk parameters, which are included in braces immediately following the first set of backticks. The first parameter indicates the programming language. The second parameter, which is optional and should be separated from the first parameter only by a space, is a chunk label. It is important that this chunk label includes no spaces and is unique to this chunk. Then, separated by commas,

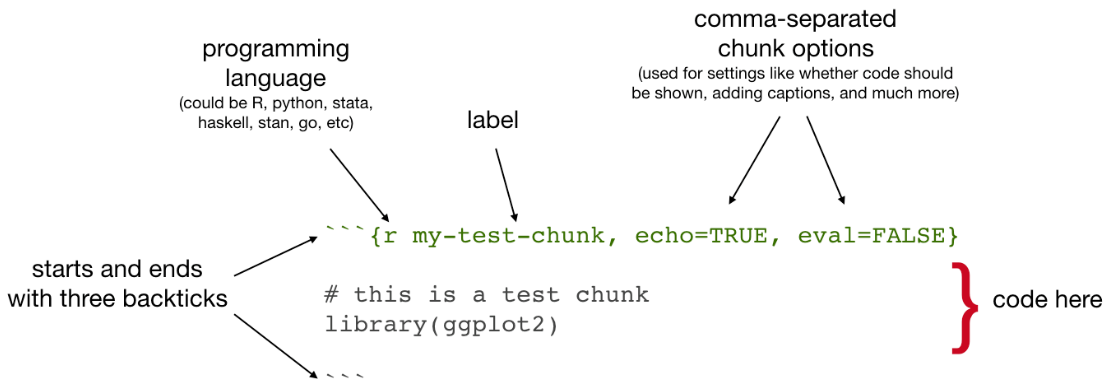


Figure 4.1: Chunk parts

are any additional parameters included. In the figure below, two examples are included: whether or not the code itself should be shown (`echo`) and whether or not the code should be evaluated or run (`eval`). Other parameters that we will see later include figure width, captions, etc.[1]

In the code chunk shown in Figure 4.1, we can see that it is loading a package library. Functions and objects loaded or created in earlier chunks are cached by default and thus held on to for use in later chunks. It is therefore quite common to have a chunk early on in your chapter (or even your whole dissertation) that loads a number of the packages you need later on. As an example, below is a short code chunk that loads a set of **R** packages that we are going to rely on for the rest of this chapter.

```
# Load packages
library(dplyr)
library(ggplot2)
library(knitr)
```

When you click the **Knit** button above in RStudio a document will be generated that includes both content as well as the output of any embedded **R** code chunks within the document. If you need a graphic or tabular material to be part of the text, you can just put it inline. If you need it to appear in the list of figures or tables, it should be placed in a code chunk.

In the remainder of this chapter, we will see how to use code chunks to include figures, load and summarise data, and present results from your analysis.

[1] More information is available at `https://yihui.org/knitr/options/`.

Figure 4.2: IHEID logo

4.2 Including external figures

First, we will treat how to include figures in *RMarkdown* in more detail. If your thesis has a lot of figures, *RMarkdown* might behave better for you than your usual word processor, which can have a tendency to . One perk is that it will automatically number the figures accordingly in each chapter. You'll also be able to create a label for each figure, add a caption, and then reference the figure in a way similar to what we saw with tables earlier. If you label your figures, you can move the figures around and *RMarkdown* will automatically adjust the numbering for you. No need for you to remember! So that you don't have to get too far into LaTeX to do this, a couple **R** functions have been created for you to assist. You'll see their use below.

4.2.1 Numbering and labelling figures

You don't need to number figures in *RMarkdown*; it'll do it automatically. And captioning a figure is awfully easy too. In the **R** chunk below, we will load in a picture that is stored as `iheid.png` in our `figures` directory. The `include_graphics()` function is from the `{knitr}` package, that does most of the heavy lifting here. We'll label the chunk 'iheidlogo' so that we can refer back to it later, and give the figure the caption "IHEID logo". You will see that here you do not need to include the parameter `echo=FALSE`, as the code including the figure is hidden by default.

```
include_graphics(path = "figures/iheid.png")
```

4.2.2 Referencing figures

Referencing figures in the text should be done with a little reference to the chunk label so that it will always refer to the right figure number, even if you add additional figures and plots before it. To reference the IHEID logo use a backslash, at-symbol, and then in parentheses

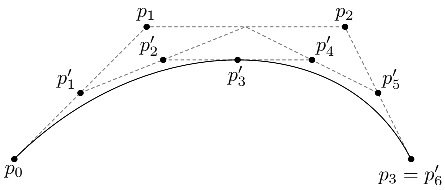


Figure 4.3: Subdiv. graph

`fig:chunk-label`, like so `\@ref(fig:iheidlogo)`. Usually some descriptor like "Figure", "Fig.", "Illustration" or other is added before this reference, so that it reads something like Figure 4.2. Note that the reference is hyperlinked in the resulting PDF, so that you can click on it to take you to the page where the original figure is printed.

4.2.3 Resizing figures

It is common to resize external image files so that they fit the format of the text. The most common way to do this was already demonstrated in the code chunk for Figure 4.1 above. There we used the parameter `out.width="\\textwidth"` to, in this case, shrink the image to the width of the text, but this same parameter specification would also expand an image to fit the width of the text where possible.

Another option is the `out.extra` chunk option. This can be used to shrink or expand an image loaded from a file more specifically by specifying `"scale= "`. Here we use the graph stored in the "subdivision.pdf" file, again found in the `figures` subdirectory. The output can be found in Fig. 4.3.

```
include_graphics("figures/subdivision.pdf")
```

We can also use the `out.extra` chunk option to enlarge figures, and even to rotate them any number of degrees around its axis. In Figure 4.4, we see an example where Figure 4.3 has been enlarged and flipped upside down.

```
include_graphics("figures/subdivision.pdf")
```

If you look closely at the chunk options, you will also see that two different captions have been provided. The `fig.scap` is a short caption that overrides the main caption, `fig.cap`, in the

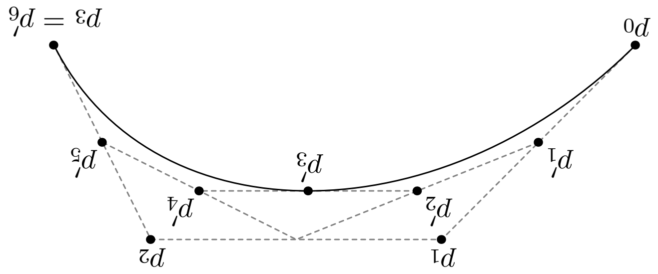


Figure 4.4: A Larger Figure, Flipped Upside Down

table of contents. This can be very useful where, for example, you need to describe the figure in a caption over several lines, details that do not need to be presented in the table of contents.

4.2.4 Placing figures

One thing that may be annoying is the way *RMarkdown* handles “floats” like tables and figures (it’s really LaTeX‘s fault). LaTeX will try to find the best place to put your object based on the text around it and, until you’re really, truly done writing, it is best to just leave it where it lies. There are some optional arguments specified in the options parameter of the `label` function. If you need to shift your figure around, it might be good to look here (you can click on the word ’here’) on tweaking the options argument.

Spacing out your chunks between paragraphs can help, as it can give LaTeX more options to find a suitable home for the figure or table, as LaTeX would otherwise try and keep all the text together, saving the image for later. A last trick is to write `\clearpage` directly in your *RMarkdown* document. This gives LaTeX a chance to catch up with all the ‘floats’ it has accumulated, and starts a new page.

4.3 Loading and exploring data

Sometimes it is not an existing image that must be imported, but instead you wish to create a table or plot of some data that you have imported. In this section, we're going to very quickly cover how to import internal and external data, how to manipulate and summarise the data, create plots from that data, and tabulate inferential results from that data.

4.3.1 Importing data

In some cases, the data you need might be available already in an **R** package. An example below is a very short code chunk that summarises a dataset that is built into **R**. Here it is particularly easy, as we do not even need to load the data (it is loaded by default).

```
summary(cars)
```

```
##      speed           dist       
##  Min.   : 4.0   Min.   :  2.00  
##  1st Qu.:12.0   1st Qu.: 26.00  
##  Median :15.0   Median : 36.00  
##  Mean   :15.4   Mean   : 42.98  
##  3rd Qu.:19.0   3rd Qu.: 56.00  
##  Max.   :25.0   Max.   :120.00
```

Othertimes you may need to load the data first before summarising it, with the function `data()`. There are an increasing number of data packages for **R** available, including several on a range of international and development topics.

The other option is to import data that resides in a file outside of **R**. Included in this template is a file called `flights.csv`. This file includes a subset of the larger dataset of information about all flights that departed from Seattle and Portland in 2014.[2] This subset includes only Portland flights and only rows that were complete with no missing values. Merges were also done with the `airports` and `airlines` data sets in the `pnwflights14` package to get more descriptive airport and airline names. We can load in this data set using the following commands:

[2] More information about this dataset and its **R** package is available at `https://github.com/ismayc/pnwflights14`.

4. Results

```
# flights.csv is in the data directory
flights <- read.csv("data/flights.csv")
```

The data is now stored in the data frame called `flights` in the cached environment for this *RMarkdown* document in **R**. To get a better feel for the variables included in this dataset we can use a variety of functions. Here we can see the dimensions (rows by columns) and also the names of the columns.

```
dim(flights)
```

```
## [1] 398  16
```

```
names(flights)
```

```
##  [1] "month"       "day"         "dep_time"    "dep_delay"   "arr_time"
##  [6] "arr_delay"   "carrier"     "tailnum"     "flight"      "dest"
## [11] "air_time"    "distance"    "hour"        "minute"      "carrier_name"
## [16] "dest_name"
```

Another good idea is to take a look at the dataset in table form. With this dataset having more than 20,000 rows, we won't explicitly show the results of the command here, so we'll use the `eval=FALSE` chunk option to make sure the following is not run when you 'knit' the document. Still, you can press the green play button at the right of the chunk to run the chunk on demand, bringing up a new tab showing the data.

```
View(flights)
```

4.3.2 Manipulating and summarising data

While not required, it is highly recommended you use the `dplyr` package to manipulate and summarize your data set as needed. It uses a syntax that is easy to understand using chaining or 'pipe' operations (`%>%`). Below I've created a few examples of using `dplyr` to get information about the Portland flights in 2014. The example we show here does the following:

- Selects only the `carrier_name` and `arr_delay` from the `flights` dataset and then assigns this subset to a new variable called `flights2`.
- Using `flights2`, we determine the largest arrival delay for each of the carriers.

```
flights2 <- flights %>%
  select(carrier_name, arr_delay)
max_delays <- flights2 %>%
  group_by(carrier_name) %>%
  summarize(max_arr_delay = max(arr_delay, na.rm = TRUE))
```

A useful function in the `knitr` package for making nice tables in *RMarkdown* is called `kable`. It is much easier to use than manually entering values into a table by copying and pasting values into Excel or LaTeX. This again goes to show how nice reproducible documents can be! The chunk option `results="asis"` makes sure the table is produced, not the code to create the table. Tables created with the `kable()` function (in `{knitr}`) can be extended in many useful (and pretty) ways with the recommended `{kableExtra}` package.

```
kable(max_delays,
  col.names = c("Airline", "Max Arrival Delay"),
  caption = "Maximum Delays by Airline",
  caption.short = "Max Delays by Airline",
  longtable = TRUE,
  booktabs = TRUE
)
```

Table 4.1: Maximum Delays by Airline

Airline	Max Arrival Delay
Alaska Airlines Inc.	181
American Airlines Inc.	72
Delta Air Lines Inc.	84
Frontier Airlines Inc.	68
Hawaiian Airlines Inc.	6
JetBlue Airways	172
SkyWest Airlines Inc.	103
Southwest Airlines Co.	315
United Air Lines Inc.	135
US Airways Inc.	347
Virgin America	22

Note that instead of adding the caption details in the chunk options, we will be adding this in the `kable()` function, which then passes this on up. The `caption.short` argument is used to include a shorter title to appear in the List of Tables. The last two options make Table 4.1 a little easier-to-read.[3]

We can further look into the properties of the largest value here for Alaska Airlines Inc. To do so, we can isolate the row corresponding to the arrival delay of 70 minutes for Alaskan in our original `flights` dataset. We see that the flight occurred on January 1st and departed a little after 1:30 am on its way to Anchorage.

```
flights %>%
  dplyr::filter(
    arr_delay == 70,
    carrier_name == "Alaska Airlines Inc."
  ) %>%
  select(-c(
    month, day, carrier, dest_name, hour,
    minute, carrier_name, arr_delay
  ))
```

[3]Note that we can create references/links to tables using a very similar syntax here to that with figures above. We can preface the reference with "Table" or "Tab." or so, and then create the reference with the format `\@ref(tab:chunk-label)`.

```
##   dep_time dep_delay arr_time tailnum flight dest air_time distance
## 1        1        96      235  N508AS    145  ANC      194     1542
```

4.3.3 Creating plots

Once data has been loaded or imported and manipulated or filtered as required, a common task is to visualise some key dimensions of the data to inform the reader. Here the package `{ggplot2}` plays nicely with `{dplyr}` and other `{tidyverse}` packages. `{ggplot2}` produces beautiful, high-quality academic visuals, and has been extended with a huge range of add-ons for a very broad variety of visualisation styles no matter what kind of data you have.

We're going to continue playing with the `flights` dataset from Chapter 4.3.1. First, let us show how we can visualize the arrival delay of all departing flights from Portland on March 3rd against time of departure. Note that once you open the plotting function with `ggplot()`, additional elements are chained not with the pipe operator `%>%` but `+`. Considerably more help than I can offer here on how to use `ggplot()` can be found online.

```
flights %>%
  dplyr::filter(month == 3, day == 3) %>%
  ggplot(aes(x = dep_time, y = arr_delay)) +
  geom_point()
```

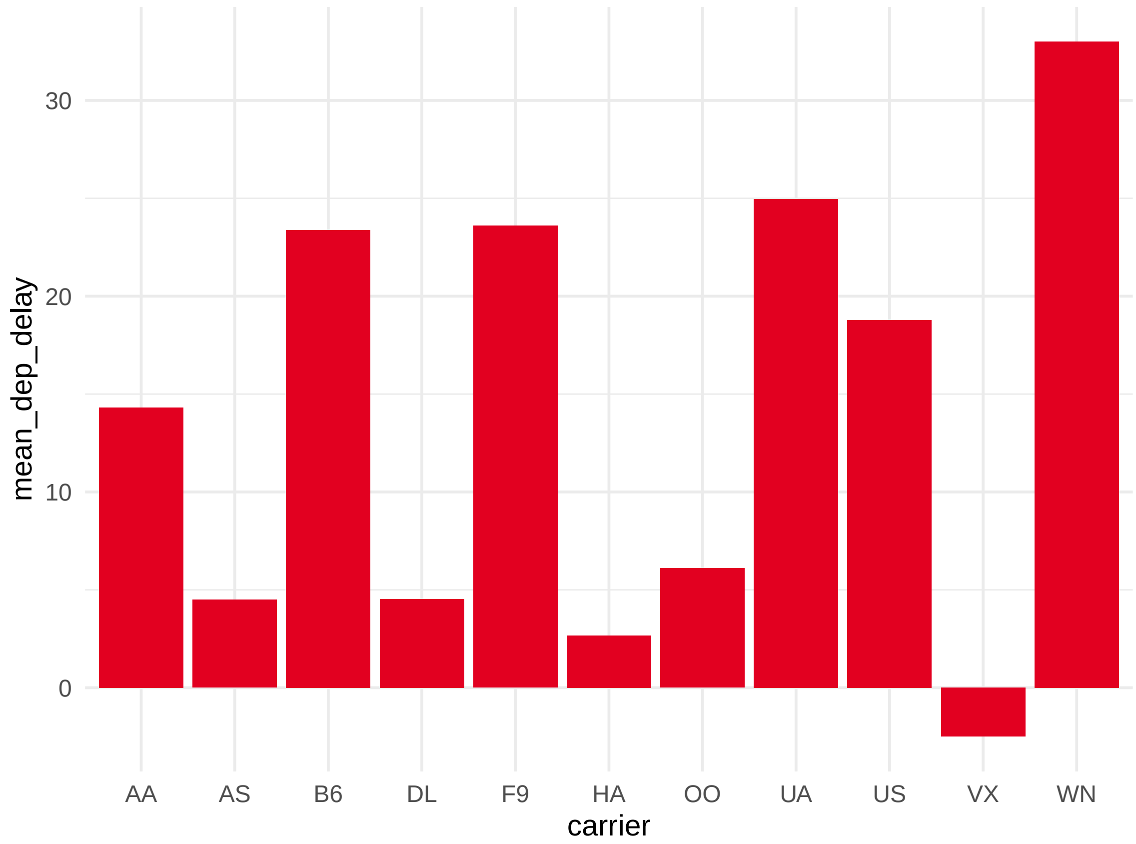
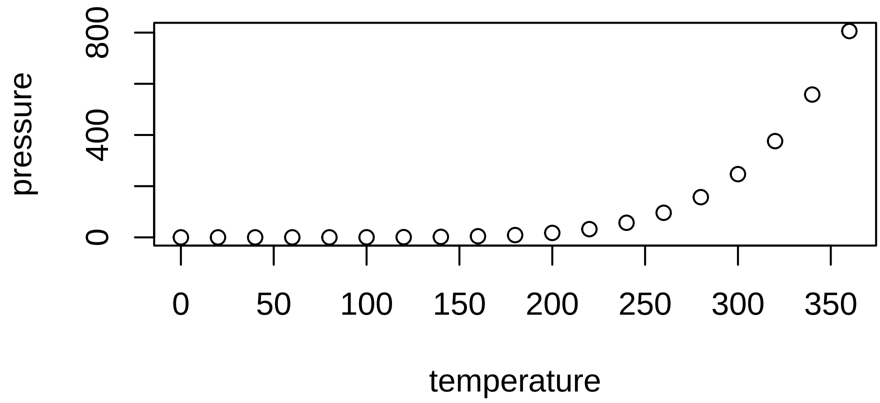


Figure 4.5: Mean Delays by Airline

Next Figure 4.5 presents a bar graph with the mean flight departure delays by airline from Portland for 2014. A table linking these carrier codes to airline names is available at `https://github.com/ismayc/pnwflights14/blob/master/data/airlines.csv`.

```
mean_delay_by_carrier <- flights %>%
  group_by(carrier) %>%
  summarize(mean_dep_delay = mean(dep_delay))
ggplot(mean_delay_by_carrier, aes(x = carrier, y = mean_dep_delay)) +
  geom_bar(position = "identity", stat = "identity",
           fill = iheiddown::iheid_palette("IHEID", 1)) +
  theme_minimal()
```

You don't have to use `{ggplot2}` though. For example, here is a way to use the base **R** graphics package to produce a plot using the built-in `pressure` dataset:



4.3.4 Tabulating inferential results

Another common task researchers have is the presentation of results obtained from applying various statistical methods to their data. Since **R** makes available a very broad range of statistical methods, and all too often these output objects in different structures and formats, there is unfortunately no single package that reliably and prettily prints results. Still, I can offer a few suggestions here that cover as much as possible, in addition to `{kable}` and `{kableExtra}` mentioned above.

- `{stargazer}` for well-formatted regression tables, with multiple models side-by-side, as well as for summary statistics tables, data frames, vectors and matrices.
- `{xtable}` offers a straightforward but extensible framework.
- `{memisc}` provides tools for the management of survey data, as well as the creation of tables of summary statistics and model estimates.
- `{Hmisc}` for data description and predictive modeling.
- `{finalfit}` brings together the day-to-day functions we use to generate final results tables and plots when modelling.
- `{tableone}` i.e., description of baseline patient characteristics.
- `{flextable}` provides a framework for easily create tables for reporting and publications (PDF documents only with package `{pagedown}`).
- `{huxtable}` creates LaTeX and HTML tables with a friendly, modern interface.

- `{texreg}`
- `{apsrtable}`
- `{arsenal}`

I (James Hollway) would welcome any feedback on any other packages you find useful (more are being released all the time), and which of these worked for your purposes.

4.3.5 Tables from external data

In addition to the tables that can be automatically generated from data in **R**, you can also create tables directly using *pandoc*. This might be useful if you don't have values specifically stored in **R**, but you'd like to display them in table form.

Below is an example.

Pay careful attention to the alignment in the table and hyphens to create the rows and columns. More information is available at `https://pandoc.org/README.html#tables`.

Table 4.2: Correlation of Inheritance Factors for Parents and Child

Factors	Correlation between Parents & Child	Inherited
Education	-0.49	Yes
Socio-Economic Status	0.28	Slight
Income	0.08	No
Family Size	0.18	Slight
Occupational Prestige	0.21	Slight

The addition of the `(\#tab:inher)` option to the end of the table caption allows us to then make a reference to Table `\@ref(tab:label)`. Note that this reference could appear anywhere throughout the document after the table has appeared.

Chapter 5

Conclusion

Appendix: The Echoes of the Code

The goal of this appendix is to echo the code you used in your thesis for a greater sense of transparency and replicability of your research. Note that `ref.labels` can be set to any label. Hence, you can filter the code you want replicated in the appendix by setting labels to the desired code chunks in the various chapters. See this excellent resource for more information.

This might be particularly useful when you perform model selection to output intermediary steps here instead of in the code to avoid cluttering your report.

```
knitr::write_bib(c(.packages(), "bookdown"), "bib/packages.bib")
knitr::include_graphics("figures/chunk-parts.png")
# Load packages
library(dplyr)
library(ggplot2)
library(knitr)
include_graphics(path = "figures/iheid.png")
include_graphics("figures/subdivision.pdf")
include_graphics("figures/subdivision.pdf")
summary(cars)
# flights.csv is in the data directory
flights <- read.csv("data/flights.csv")
dim(flights)
names(flights)
View(flights)
flights2 <- flights %>%
  select(carrier_name, arr_delay)
```

Appendix

```r
max_delays <- flights2 %>%
  group_by(carrier_name) %>%
  summarize(max_arr_delay = max(arr_delay, na.rm = TRUE))
kable(max_delays,
  col.names = c("Airline", "Max Arrival Delay"),
  caption = "Maximum Delays by Airline",
  caption.short = "Max Delays by Airline",
  longtable = TRUE,
  booktabs = TRUE
)
flights %>%
  dplyr::filter(
    arr_delay == 70,
    carrier_name == "Alaska Airlines Inc."
  ) %>%
  select(-c(
    month, day, carrier, dest_name, hour,
    minute, carrier_name, arr_delay
  ))
flights %>%
  dplyr::filter(month == 3, day == 3) %>%
  ggplot(aes(x = dep_time, y = arr_delay)) +
  geom_point()
mean_delay_by_carrier <- flights %>%
  group_by(carrier) %>%
  summarize(mean_dep_delay = mean(dep_delay))
ggplot(mean_delay_by_carrier, aes(x = carrier, y = mean_dep_delay)) +
  geom_bar(position = "identity", stat = "identity",
           fill = iheiddown::iheid_palette("IHEID", 1)) +
```

```
  theme_minimal()

plot(pressure)
```

Appendix: The Echoes of the Code redux

Add as many appendices as you like.

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