

# Relationships

## Session 7

PMAP 8921: Data Visualization with R  
Andrew Young School of Policy Studies  
Fall 2023

# Plan for today

**The dangers of dual y-axes**

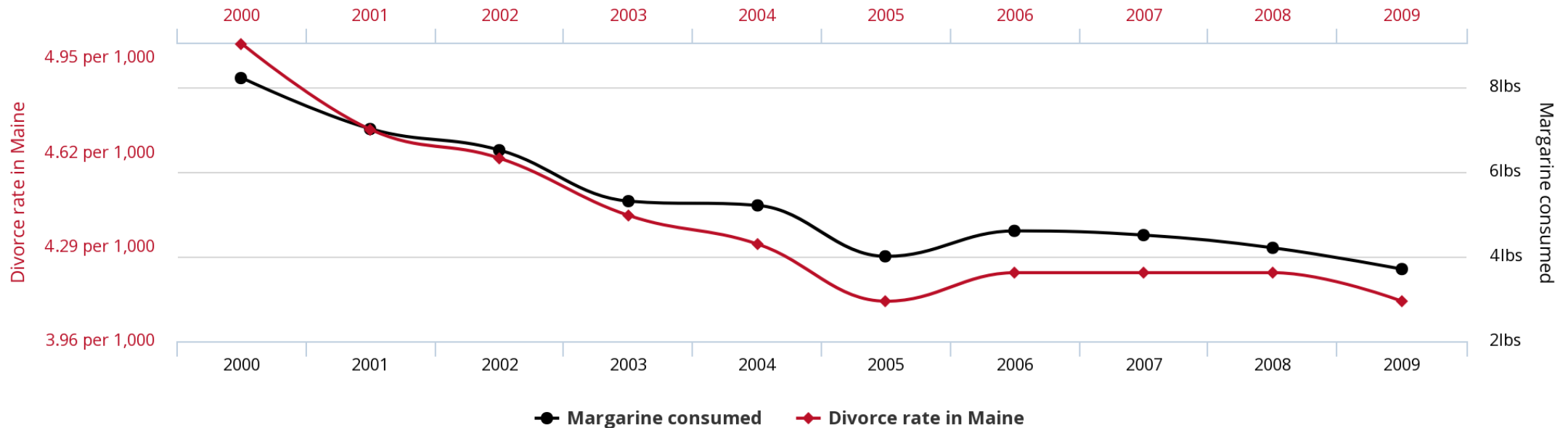
**Visualizing correlations**

**Visualizing regressions**

# The dangers of dual y-axes

# Stop eating margarine!

## Divorce rate in Maine correlates with Per capita consumption of margarine



tylervigen.com

Source: Tyler Vigen's spurious correlations

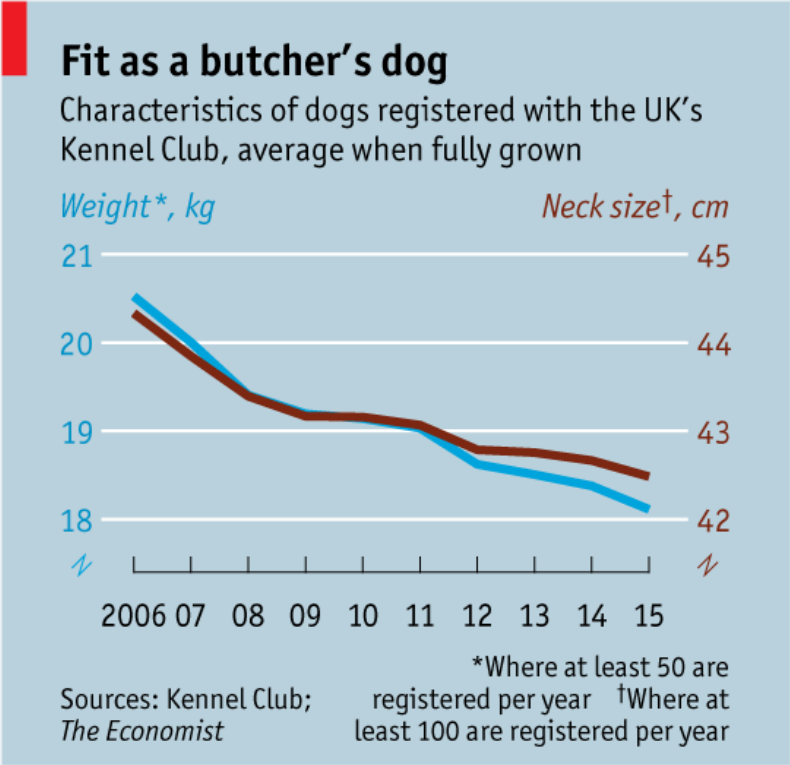
# Why not use double y-axes?

**You have to choose where the y-axes start and stop, which means...**

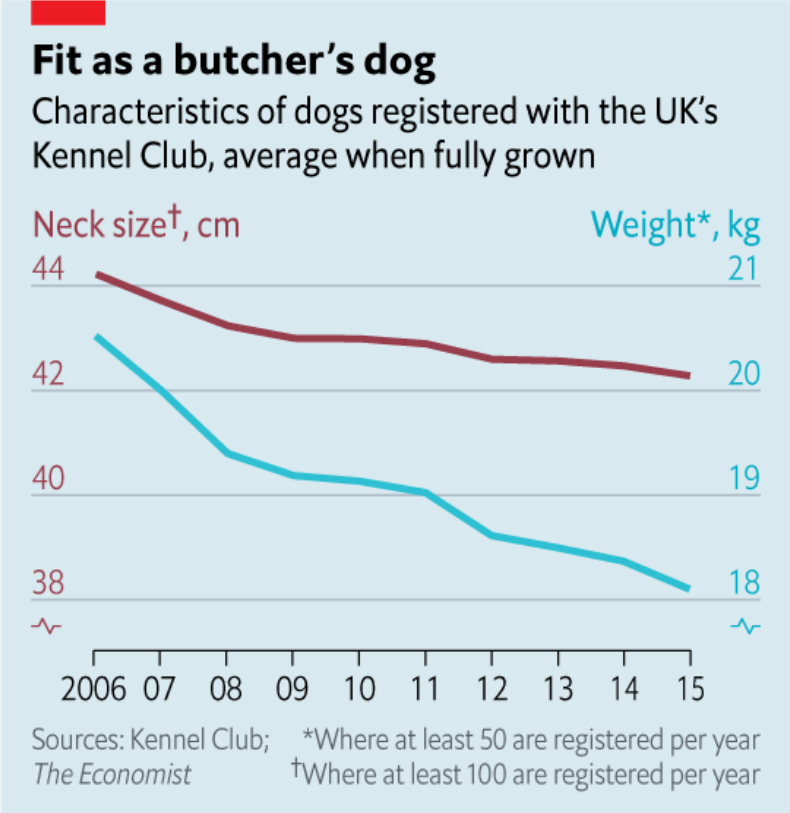
**...you can force the two trends to line up however you want!**

# It even happens in *The Economist*!

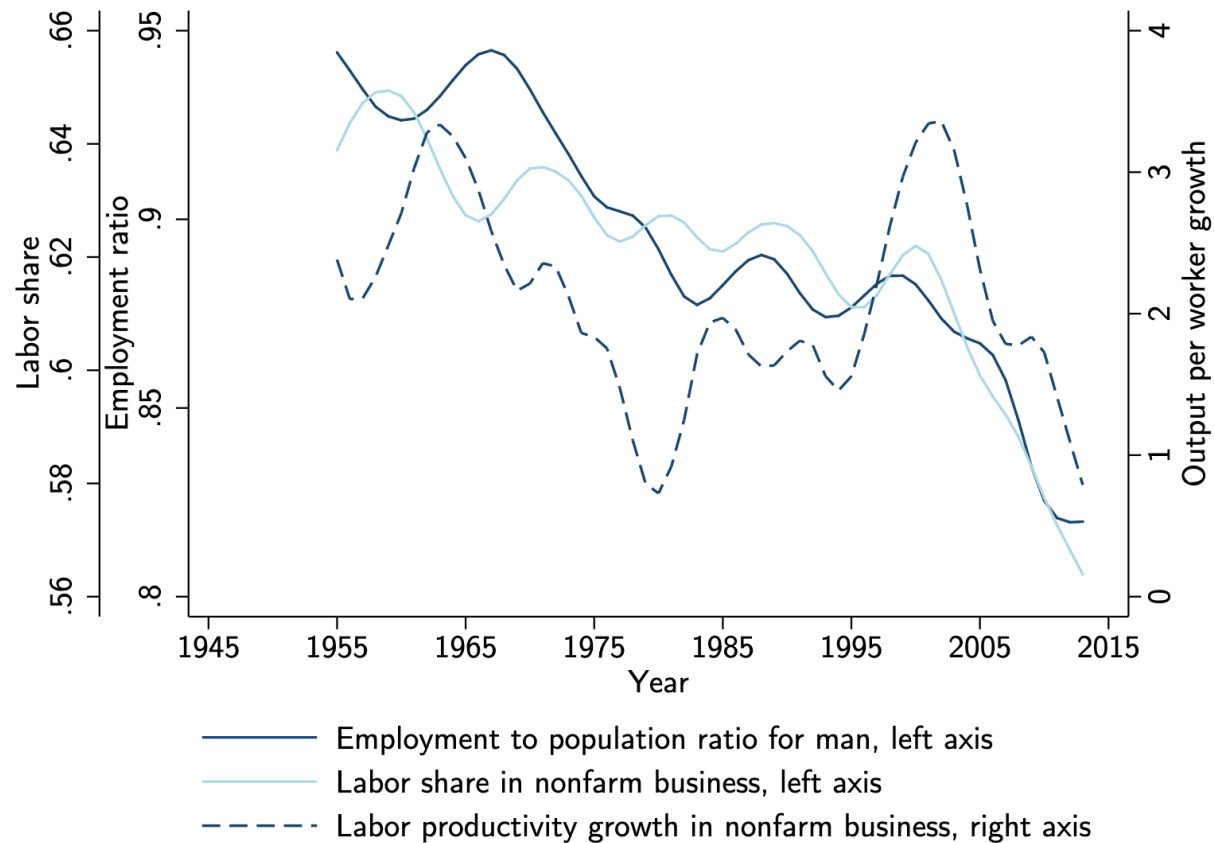
## Original



## Better



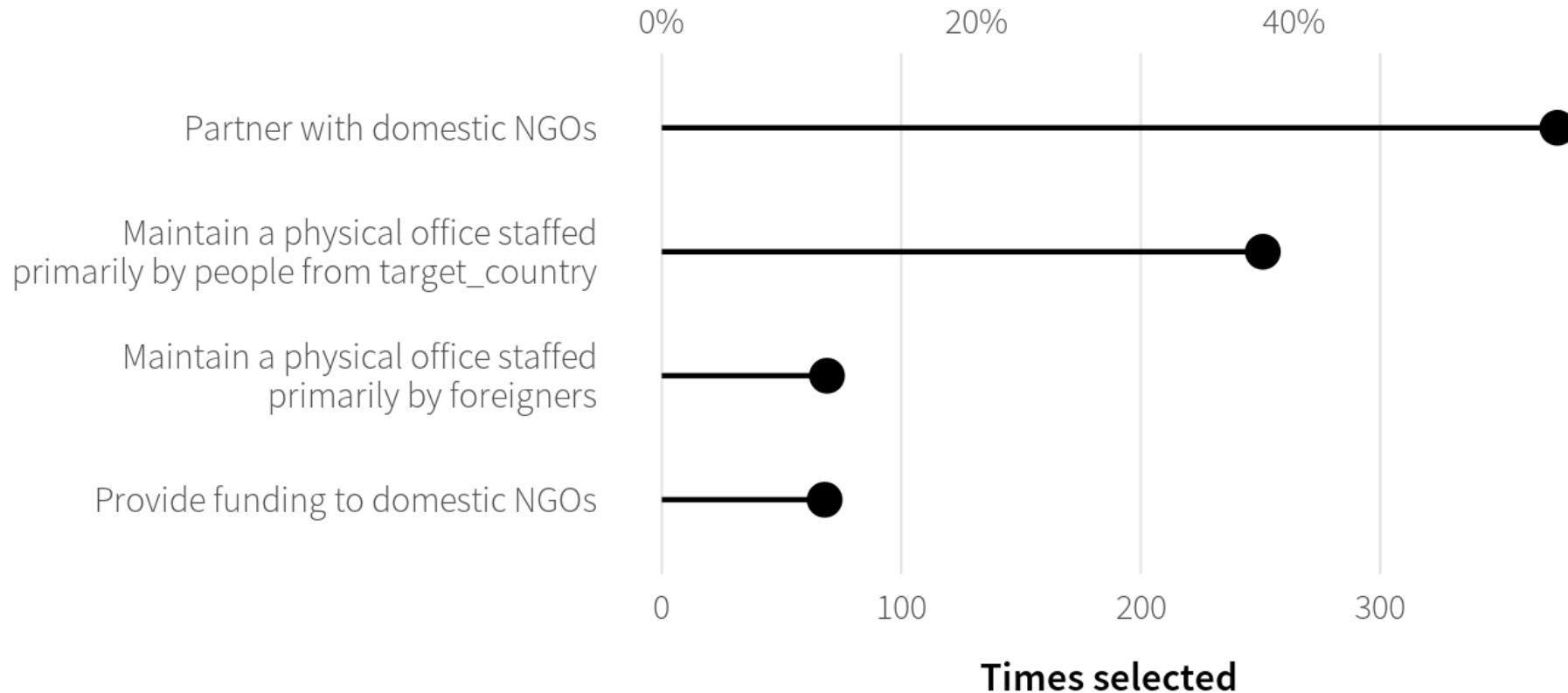
# The rare triple y-axis!



Source: Daron Acemoglu and Pascual Restrepo, "The Race Between Man and Machine: Implications of Technology for Growth, Factor Shares and Employment"

# When is it legal?

## When the two axes measure the same thing

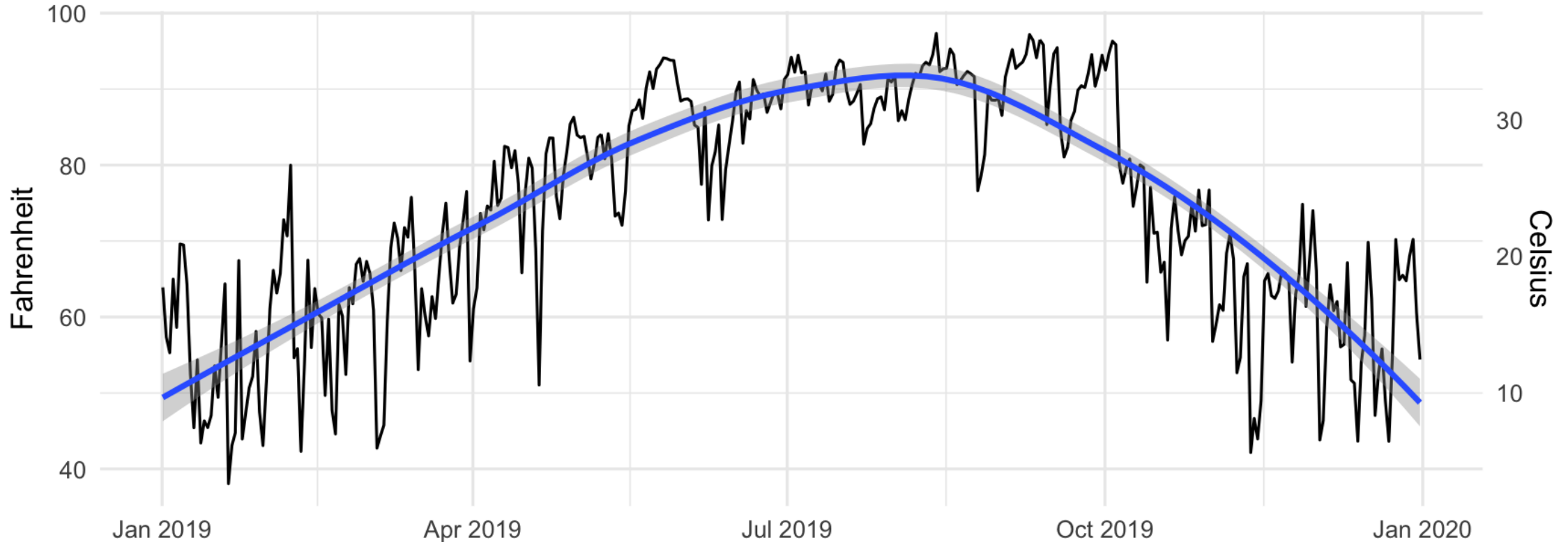




# When is it legal?

## Daily high temperatures in Atlanta

January 1 2019–December 31, 2019

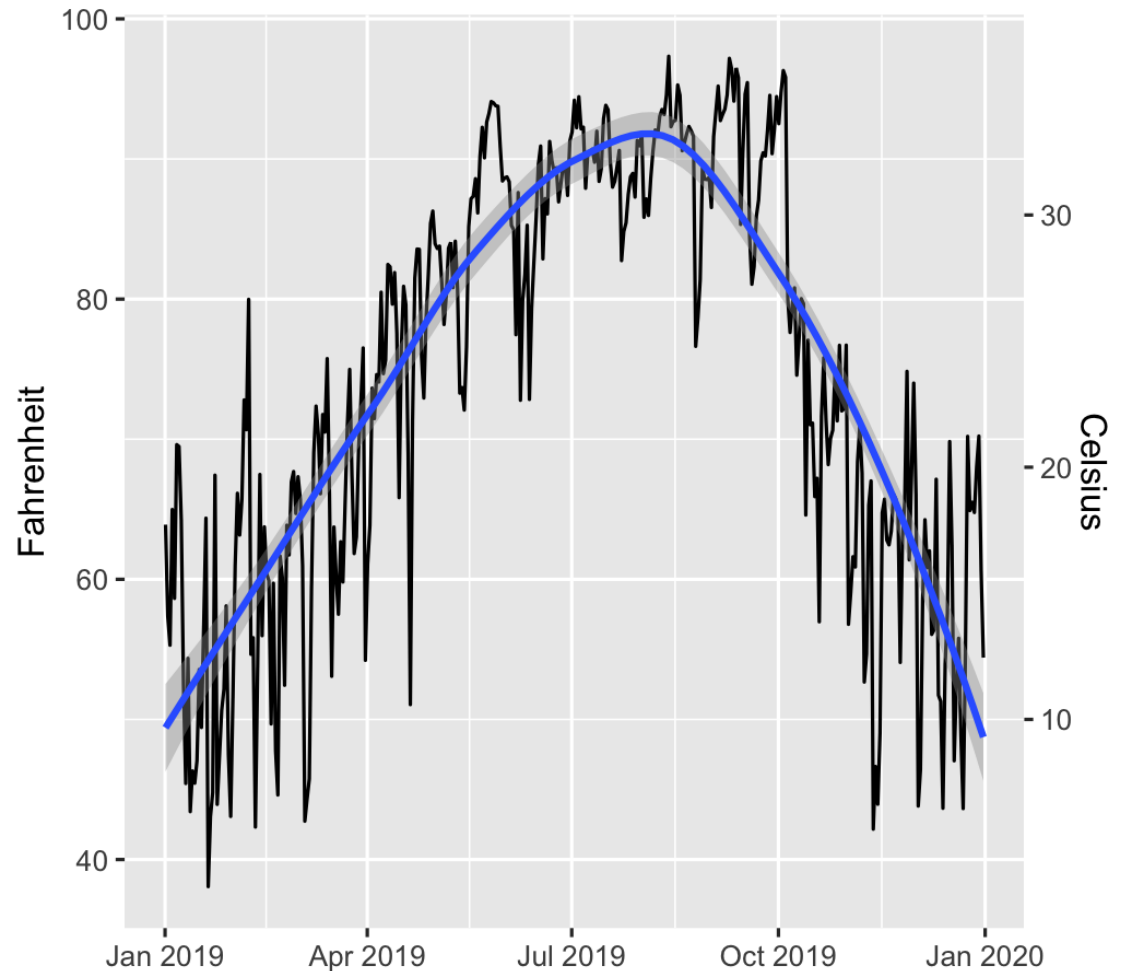


Source: Dark Sky

# Adding a second scale in R

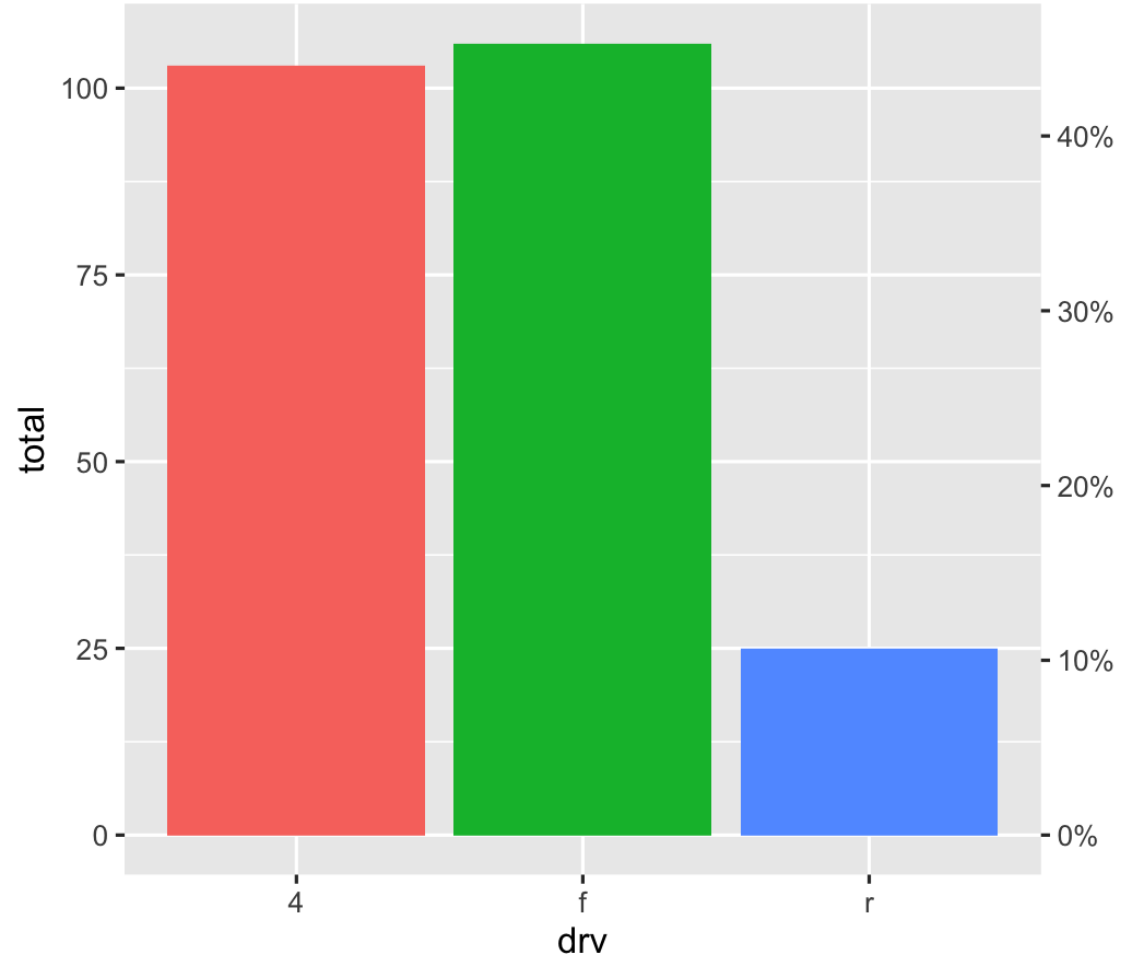
```
# From the uncertainty example
weather_atl <-
  read_csv("data/atl-weather-2019.csv")

ggplot(weather_atl,
        aes(x = time, y = temperatureHigh)) +
  geom_line() +
  geom_smooth() +
  scale_y_continuous(
    sec.axis =
      sec_axis(trans = ~ (32 - .) * -5/9,
               name = "Celsius")
  ) +
  labs(x = NULL, y = "Fahrenheit")
```

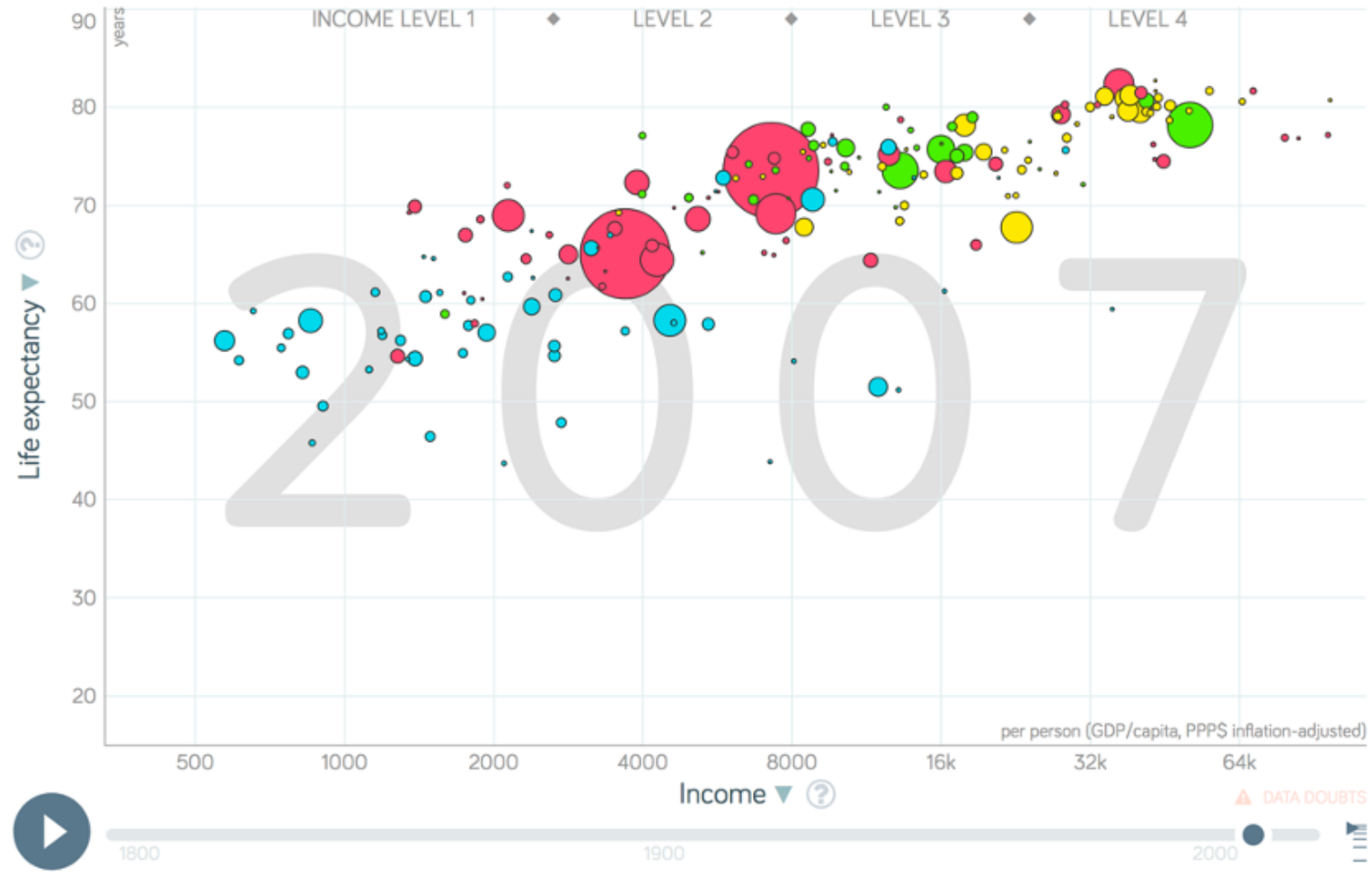


# Adding a second scale in R

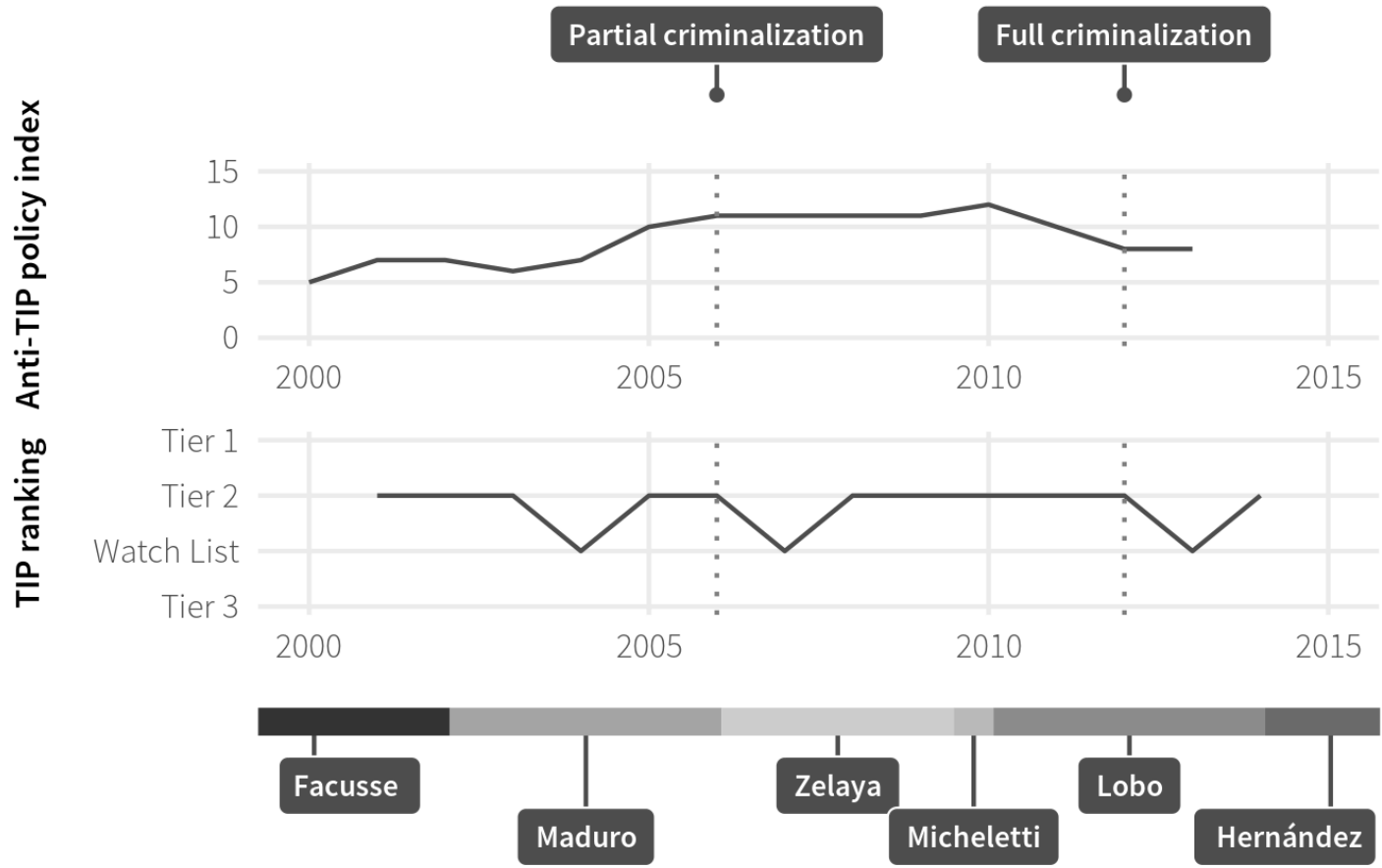
```
car_counts <- mpg %>%  
  group_by(drv) %>%  
  summarize(total = n())  
  
total_cars <- sum(car_counts$total)  
  
ggplot(car_counts,  
  aes(x = drv, y = total,  
      fill = drv)) +  
  geom_col() +  
  scale_y_continuous(  
    sec.axis = sec_axis(  
      trans = ~ . / total_cars,  
      labels = scales::label_percent()  
    ) +  
  guides(fill = "none")
```



# Alternative 1: Use another aesthetic



# Alternative 2: Use multiple plots



Anti-trafficking policy timeline in Honduras

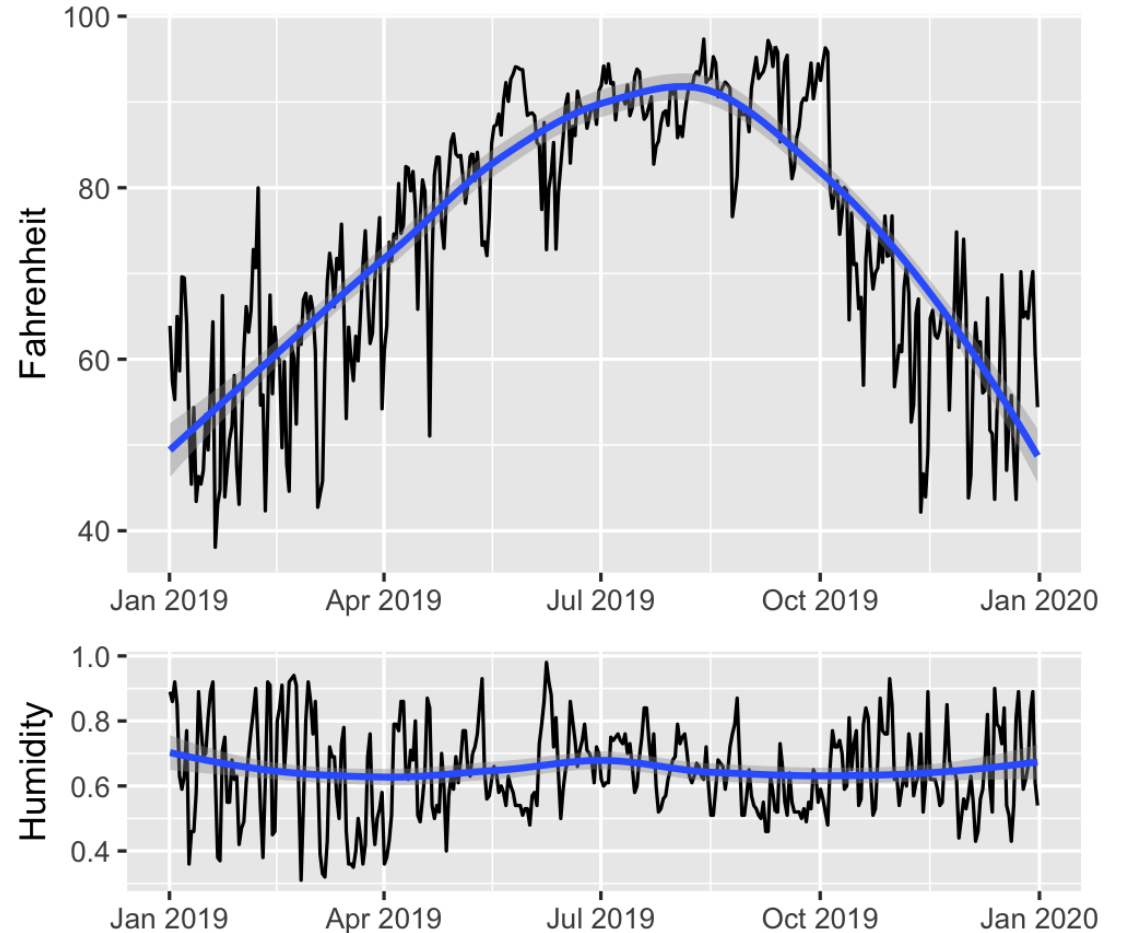
# Alternative 2: Use multiple plots

```
library(patchwork)

temp_plot <- ggplot(weather_atl,
  aes(x = time,
      y = temperatureHigh)) +
  geom_line() + geom_smooth() +
  labs(x = NULL, y = "Fahrenheit")

humid_plot <- ggplot(weather_atl,
  aes(x = time,
      y = humidity)) +
  geom_line() + geom_smooth() +
  labs(x = NULL, y = "Humidity")

temp_plot + humid_plot +
  plot_layout(ncol = 1,
    heights = c(0.7, 0.3))
```



# Visualizing correlations

# What is correlation?

$$r_{x,y} = \frac{\text{cov}(x, y)}{\sigma_x \sigma_y}$$

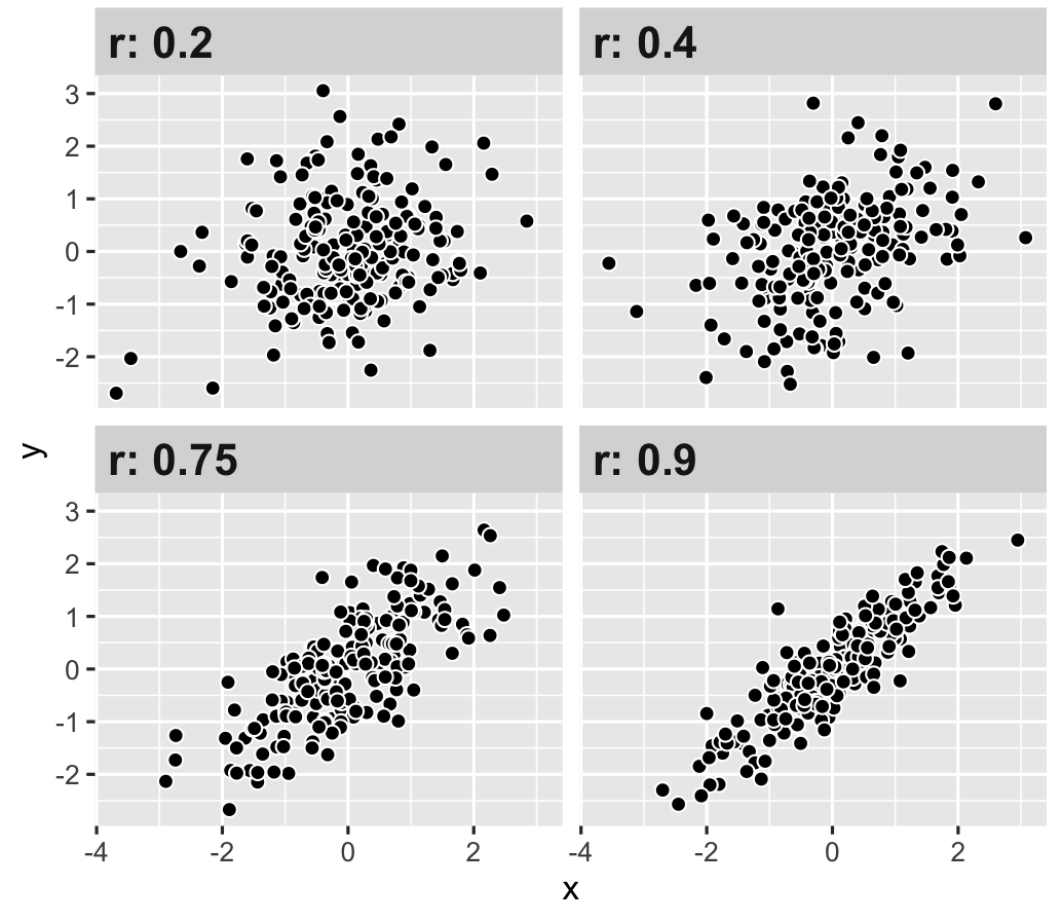
As the value of X goes up,  
Y tends to go up (or down)  
a lot/a little/not at all

Says nothing about *how much*  
Y changes when X changes



# Correlation values

<b>r</b>	<b>Rough meaning</b>
$\pm 0.1-0.3$	Modest
$\pm 0.3-0.5$	Moderate
$\pm 0.5-0.8$	Strong
$\pm 0.8-0.9$	Very strong

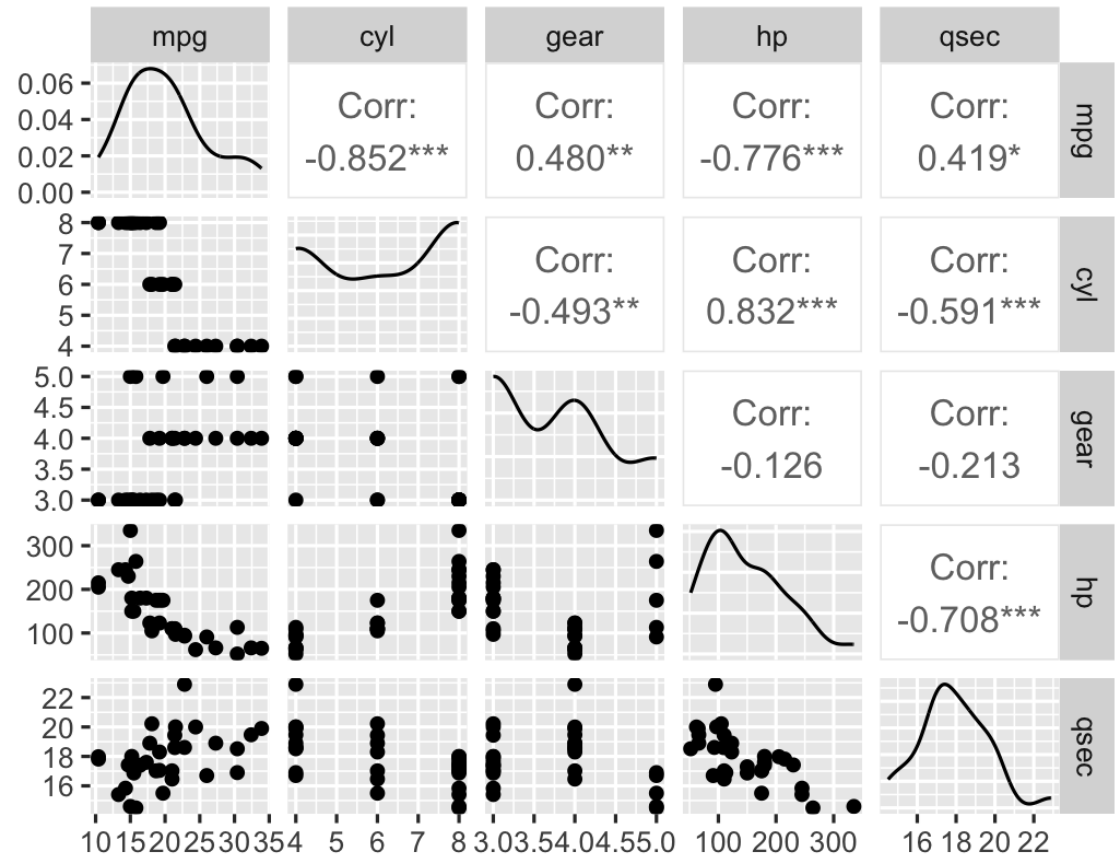


# Scatterplot matrices

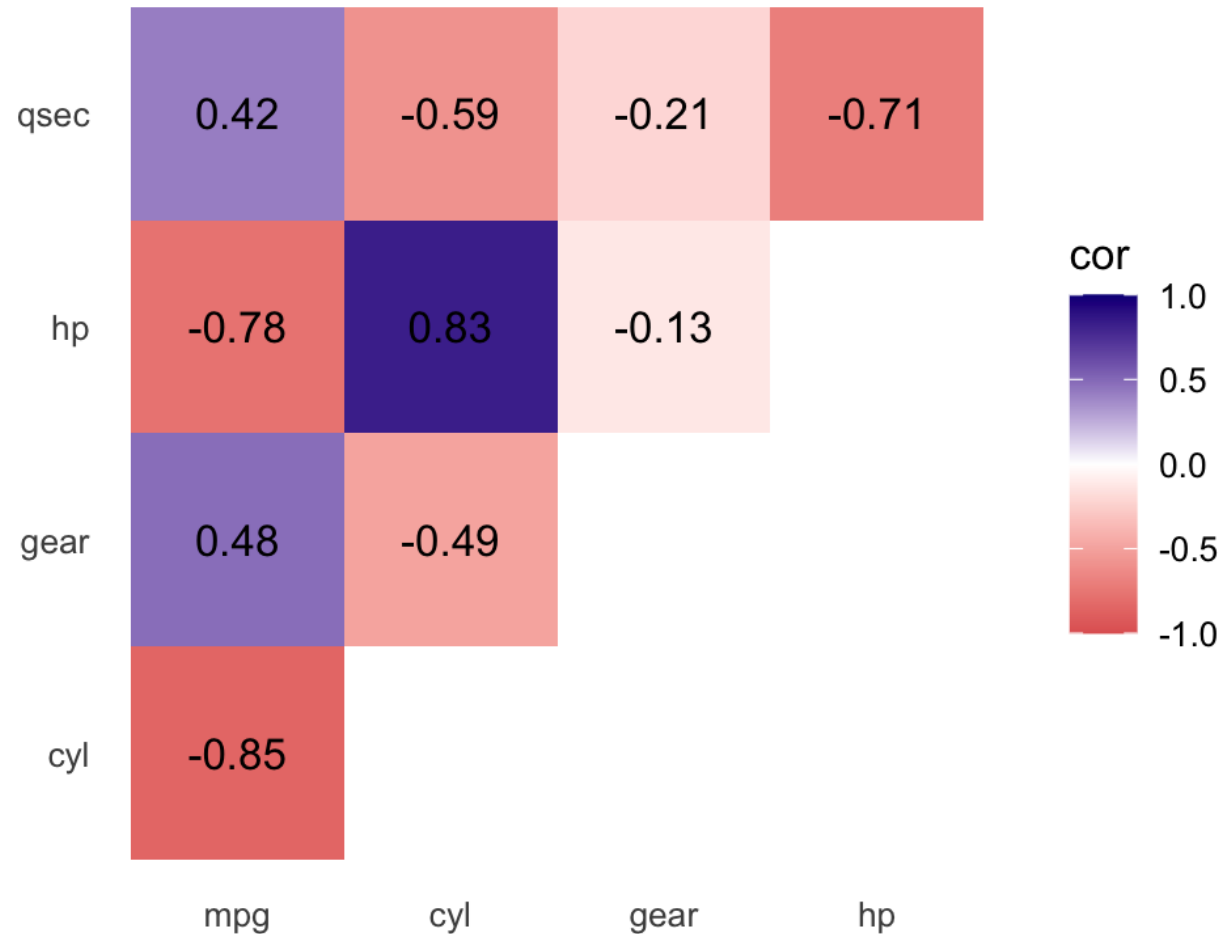
```
library(GGally)

cars_smaller <- mtcars %>%
  select(mpg, cyl, gear, hp, qsec)

ggpairs(cars_smaller)
```



# Correlograms: Heatmaps

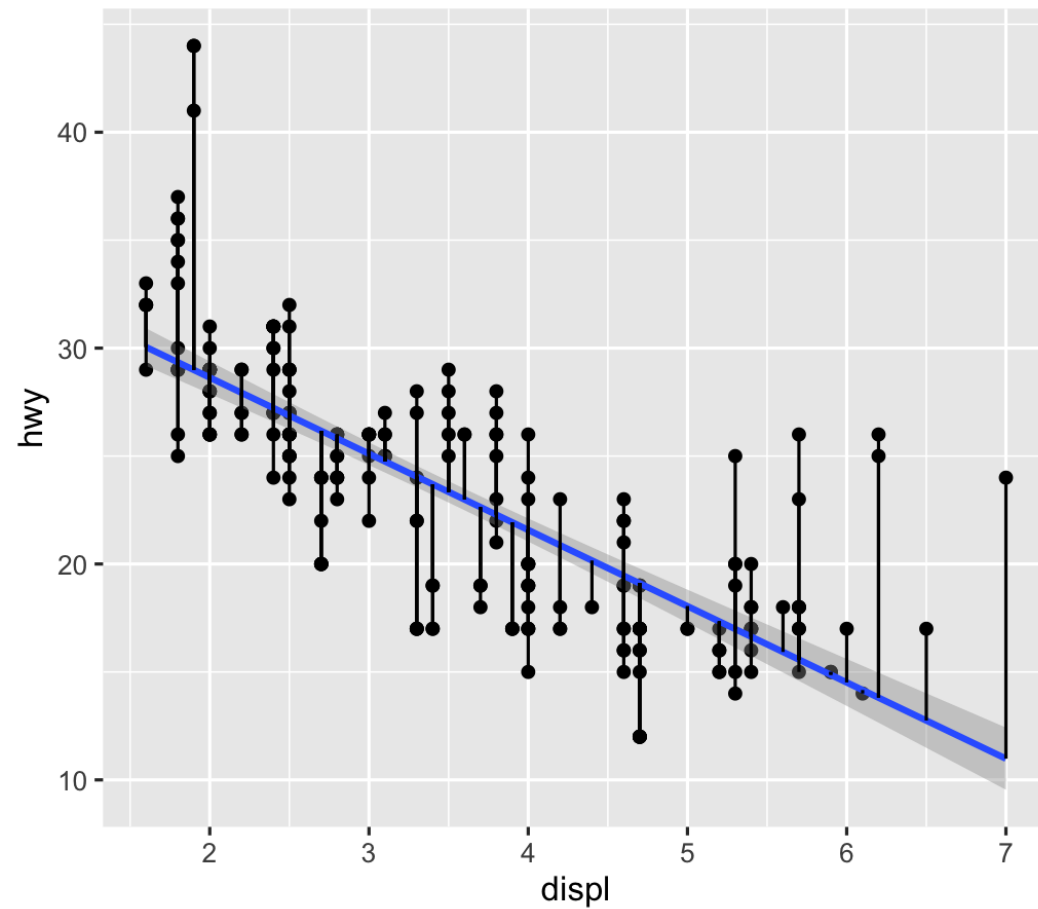
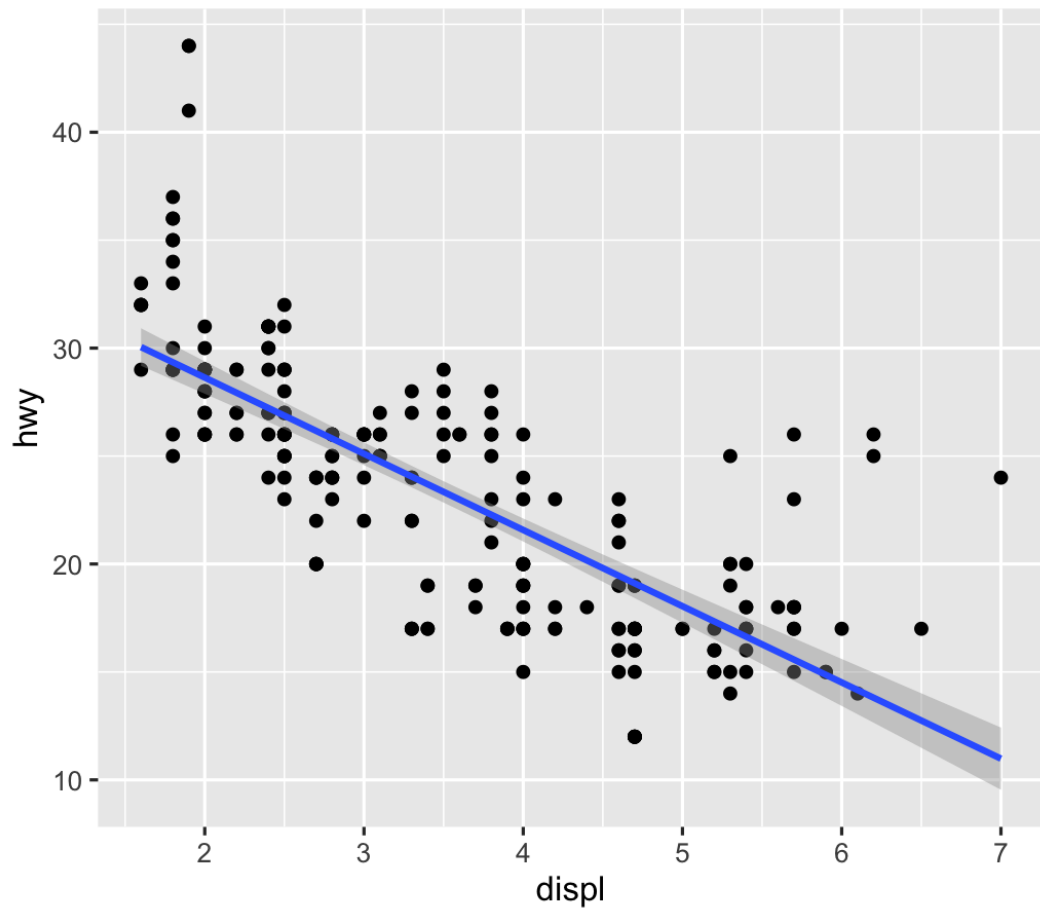


# Correlograms: Points



# Visualizing regressions

# Drawing lines



# Drawing lines with math

$$y = mx + b$$

---

$y$  A number

$x$  A number

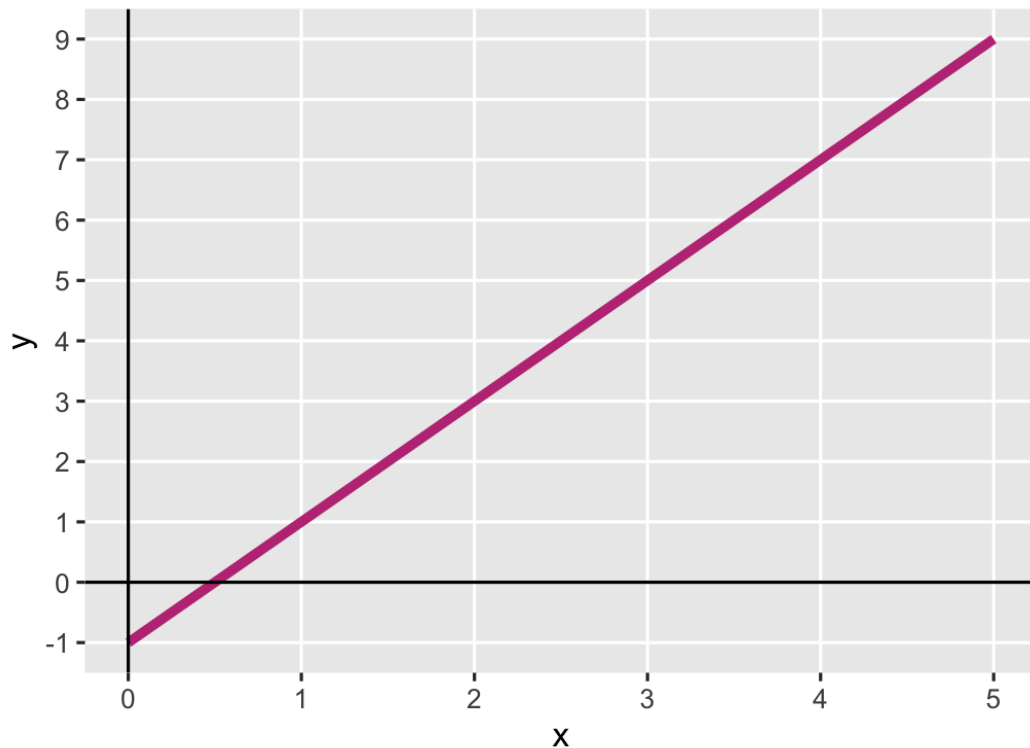
$m$  Slope ( $\frac{\text{rise}}{\text{run}}$ )

$b$  y-intercept

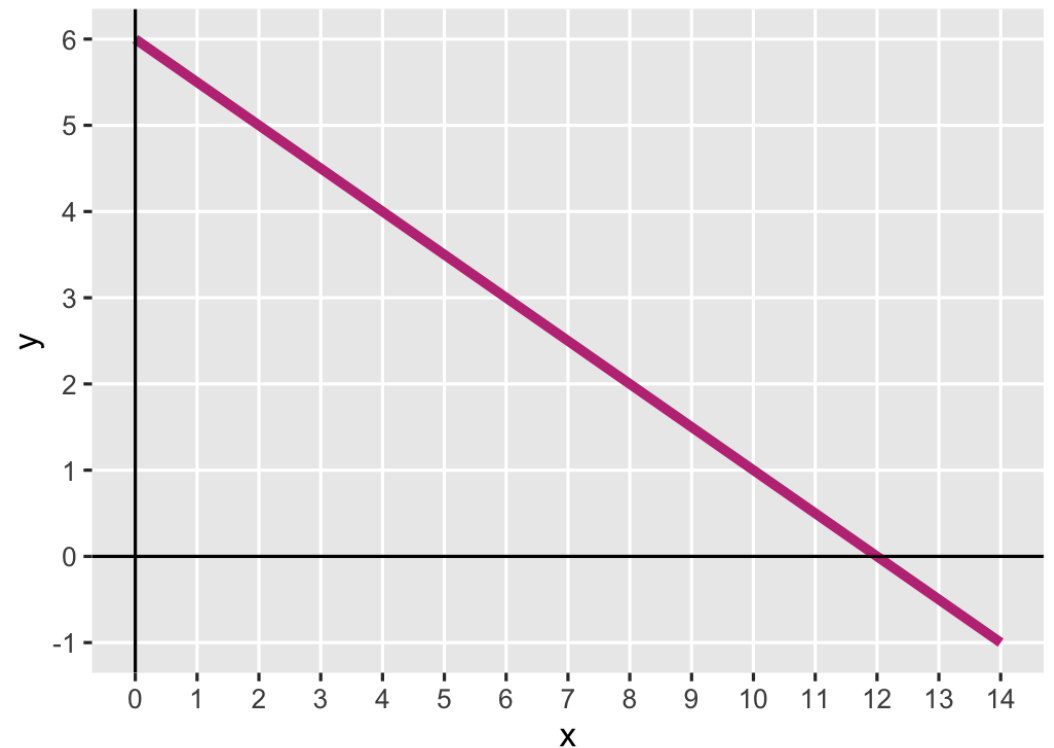
---

# Slopes and intercepts

$$y = 2x - 1$$



$$y = -0.5x + 6$$





# Drawing lines with stats

$$\hat{y} = \beta_0 + \beta_1 x_1 + \varepsilon$$

---

$y$	$\hat{y}$	Outcome variable (DV)
$x$	$x_1$	Explanatory variable (IV)
$m$	$\beta_1$	Slope
$b$	$\beta_0$	y-intercept
	$\varepsilon$	Error (residuals)

---

# Building models in R

```
name_of_model <- lm(<Y> ~ <X>, data = <DATA>)  
summary(name_of_model)  # See model details
```

```
library(broom)
```

```
# Convert model results to a data frame for plotting
```

```
tidy(name_of_model)
```

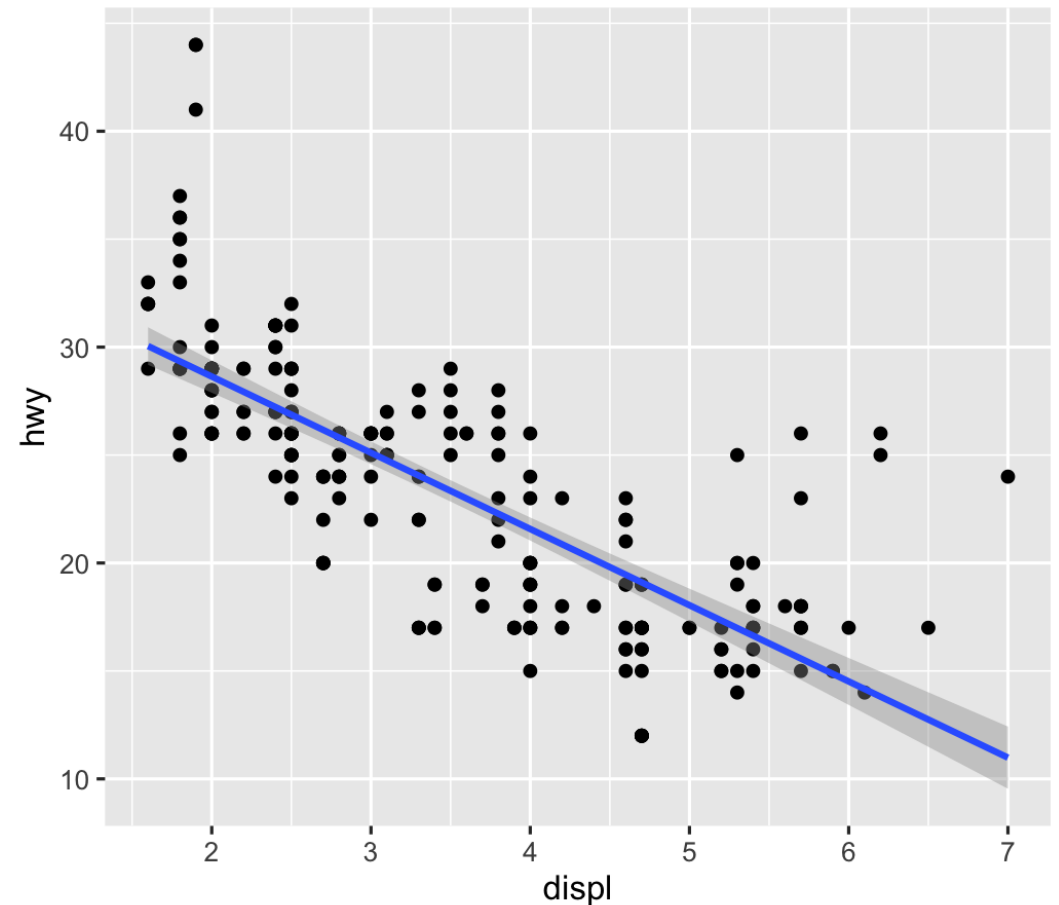
```
# Convert model diagnostics to a data frame
```

```
glance(name_of_model)
```

# Modeling displacement and MPG

$$\widehat{hwy} = \beta_0 + \beta_1 \text{displ} + \varepsilon$$

```
car_model <- lm(hwy ~ displ,  
                data = mpg)
```



# Modeling displacement and MPG

```
tidy(car_model, conf.int = TRUE)
```

```
## # A tibble: 2 × 7
##   term      estimate std.error statistic  p.value conf.low conf.high
##   <chr>      <dbl>    <dbl>    <dbl>    <dbl>    <dbl>    <dbl>
## 1 (Intercept)  35.7      0.720     49.6 2.12e-125  34.3     37.1
## 2 displ      -3.53     0.195    -18.2 2.04e- 46  -3.91    -3.15
```

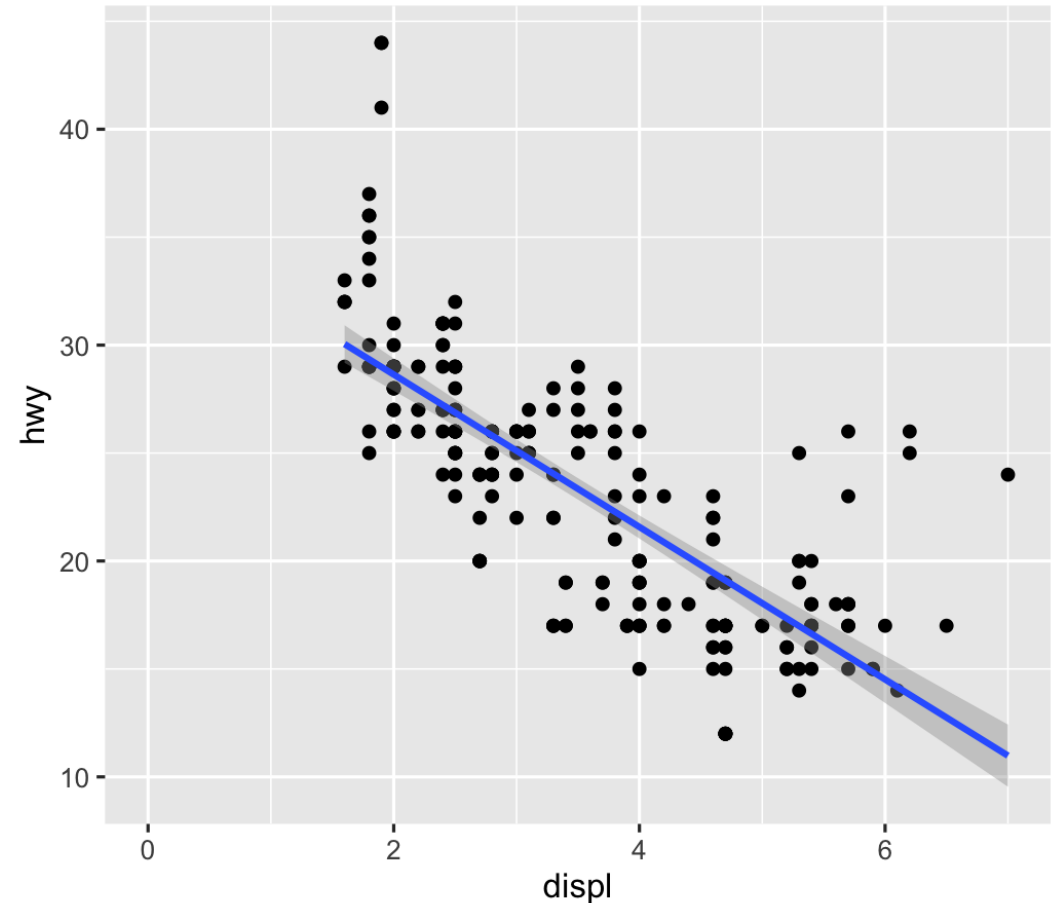
```
glance(car_model)
```

```
## # A tibble: 1 × 12
##   r.squared adj.r.squared sigma statistic  p.value    df logLik  AIC  BIC
##   <dbl>      <dbl> <dbl>    <dbl>    <dbl> <dbl> <dbl> <dbl> <dbl>
## 1  0.587      0.585  3.84     329. 2.04e-46     1 -646. 1297. 1308.
## # i 3 more variables: deviance <dbl>, df.residual <int>, nobs <int>
```

# Translating results to math

```
## # A tibble: 2 × 2
##   term      estimate
##   <chr>      <dbl>
## 1 (Intercept) 35.7
## 2 displ      -3.53
```

$$\hat{hwy} = 35.7 + (-3.53) \times displ + \varepsilon$$



# Template for single variables

A one unit increase in  $X$  is *associated* with a  $\beta_1$  increase (or decrease) in  $Y$ , on average

$$\hat{h\hat{w}y} = \beta_0 + \beta_1 \text{displ} + \varepsilon$$

$$\hat{h\hat{w}y} = 35.7 + (-3.53) \times \text{displ} + \varepsilon$$

**This is easy to visualize! It's a line!**

# Multiple regression

We're not limited to just one explanatory variable!

$$\hat{y} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \varepsilon$$

```
car_model_big <- lm(hwy ~ displ + cyl + drv,  
                    data = mpg)
```

$$\hat{hwy} = \beta_0 + \beta_1 \text{displ} + \beta_2 \text{cyl} + \beta_3 \text{drv:f} + \beta_4 \text{drv:r} + \varepsilon$$

# Modeling lots of things and MPG

```
tidy(car_model_big, conf.int = TRUE)
```

```
## # A tibble: 5 × 7
##   term          estimate std.error statistic  p.value conf.low conf.high
##   <chr>          <dbl>    <dbl>    <dbl>    <dbl>    <dbl>    <dbl>
## 1 (Intercept)    33.1      1.03     32.1  9.49e-87  31.1     35.1
## 2 displ         -1.12     0.461    -2.44  1.56e- 2  -2.03    -0.215
## 3 cyl           -1.45     0.333    -4.36  1.99e- 5  -2.11    -0.796
## 4 drv:f          5.04     0.513     9.83  3.07e-19   4.03     6.06
## 5 drv:r          4.89     0.712     6.86  6.20e-11   3.48     6.29
```

$$\hat{hwy} = 33.1 + (-1.12) \times displ + (-1.45) \times cyl + (5.04) \times drv:f + (4.89) \times drv:r + \varepsilon$$



# Sliders and switches



# Sliders and switches

**Categorical  
variables**



**Continuous  
variables**



# Template for continuous variables

*Holding everything else constant, a one unit increase in X is associated with a  $\beta_n$  increase (or decrease) in Y, on average*

$$\hat{hwy} = 33.1 + (-1.12) \times displ + (-1.45) \times cyl + (5.04) \times drv:f + (4.89) \times drv:r + \varepsilon$$

**On average, a one unit increase in cylinders is associated with 1.45 lower highway MPG, holding everything else constant**

# Template for categorical variables

*Holding everything else constant,  $Y$  is  $\beta_n$  units larger (or smaller) in  $X_n$ , compared to  $X_{\text{omitted}}$ , on average*

$$\hat{h\hat{w}y} = 33.1 + (-1.12) \times \text{displ} + (-1.45) \times \text{cyl} + (5.04) \times \text{drv:f} + (4.89) \times \text{drv:r} + \varepsilon$$

**On average, front-wheel drive cars have 5.04 higher highway MPG than 4-wheel-drive cars, holding everything else constant**

# Good luck visualizing all this!

**You can't just draw a line!  
There are too many moving parts!**

# Main problems

Each coefficient has its own estimate and standard errors

**Solution:** Plot the coefficients and their errors with a *coefficient plot*

The results change as you move each slider up and down and flip each switch on and off

**Solution:** Plot the *marginal effects* for the coefficients you're interested in

# Coefficient plots

Convert the model results to a data frame with `tidy()`

```
car_model_big <- lm(hwy ~ displ + cyl + drv, data = mpg)

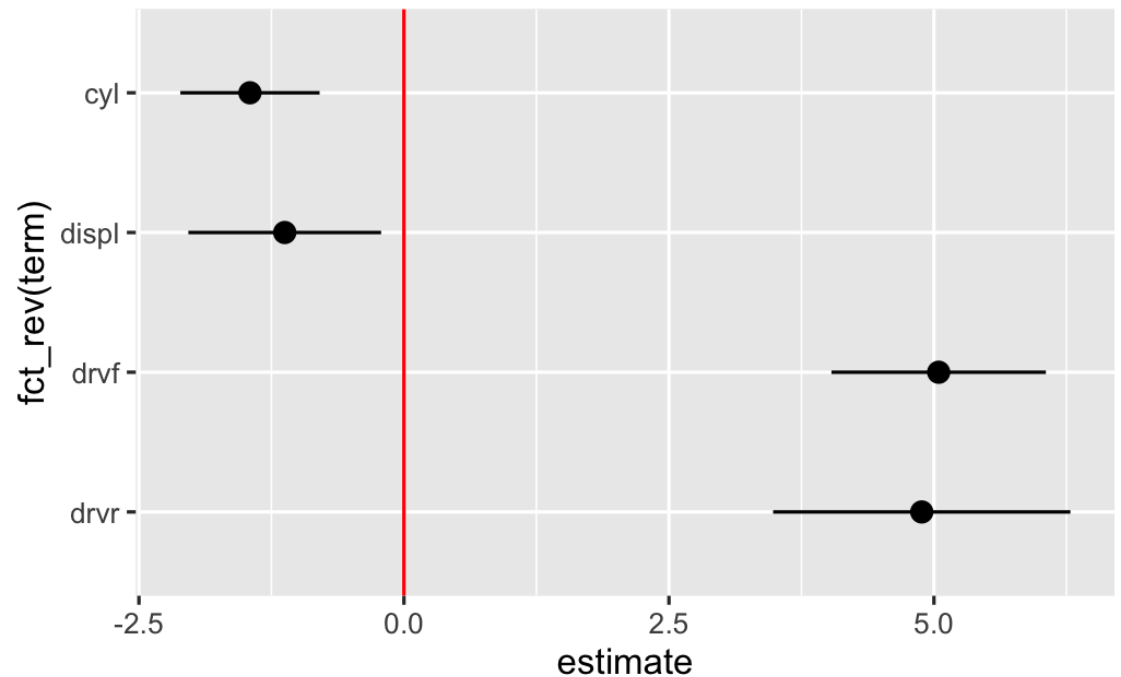
car_coefs <- tidy(car_model_big, conf.int = TRUE) %>%
  filter(term != "(Intercept)") # We can typically skip plotting the intercept, so remove it
car_coefs
```

```
## # A tibble: 4 × 7
##   term estimate std.error statistic p.value conf.low conf.high
##   <chr>    <dbl>    <dbl>    <dbl>    <dbl>    <dbl>    <dbl>
## 1 displ    -1.12     0.461    -2.44  1.56e- 2    -2.03    -0.215
## 2 cyl      -1.45     0.333    -4.36  1.99e- 5    -2.11    -0.796
## 3 drvf      5.04     0.513     9.83  3.07e-19     4.03     6.06
## 4 drvr      4.89     0.712     6.86  6.20e-11     3.48     6.29
```

# Coefficient plots

Plot the estimate and confidence intervals with `geom_pointrange()`

```
ggplot(car_coefs,  
       aes(x = estimate,  
           y = fct_rev(term))) +  
  geom_pointrange(aes(xmin = conf.low,  
                     xmax = conf.high)) +  
  geom_vline(xintercept = 0, color = "red")
```





# Marginal effects plots

Remember that we interpret individual coefficients while holding the others constant

We move one slider while leaving all the other sliders and switches alone

Same principle applies to visualizing the effect

Plug a bunch of values into the model and find the predicted outcome

Plot the values and predicted outcome

# Marginal effects plots

Create a data frame of values you want to manipulate and values you want to hold constant

**Must include all the explanatory variables in the model**

# Marginal effects plots

```
cars_new_data <- tibble(displ = seq(2, 7, by = 0.1),  
                        cyl = mean(mpg$cyl),  
                        drv = "f")
```

```
head(cars_new_data)
```

```
## # A tibble: 6 × 3  
##   displ   cyl drv  
##   <dbl> <dbl> <chr>  
## 1     2   5.89 f  
## 2   2.1   5.89 f  
## 3   2.2   5.89 f  
## 4   2.3   5.89 f  
## 5   2.4   5.89 f  
## 6   2.5   5.89 f
```

# Marginal effects plots

Plug each of those rows of data into the model with `augment()`

```
predicted_mpg <- augment(car_model_big, newdata = cars_new_data,  
                          se_fit = TRUE)
```

```
head(predicted_mpg)
```

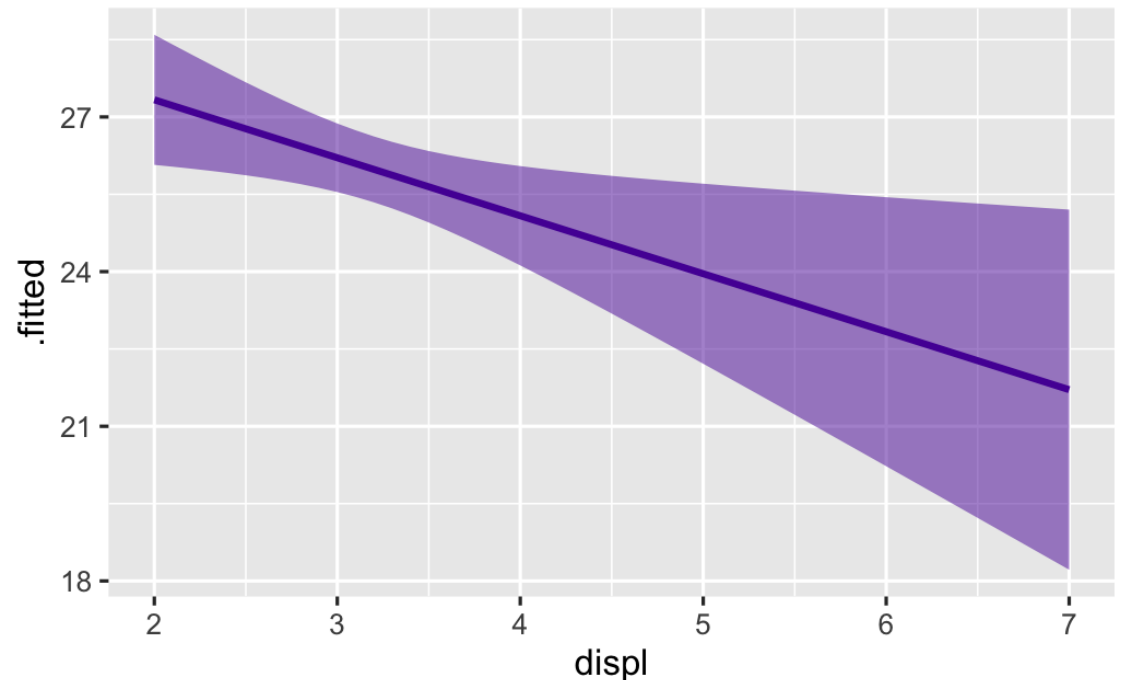
```
## # A tibble: 6 × 5  
##   displ   cyl drv   .fitted .se.fit  
##   <dbl> <dbl> <chr>   <dbl>   <dbl>  
## 1     2   5.89 f     27.3    0.644  
## 2    2.1  5.89 f     27.2    0.604  
## 3    2.2  5.89 f     27.1    0.566  
## 4    2.3  5.89 f     27.0    0.529  
## 5    2.4  5.89 f     26.9    0.494  
## 6    2.5  5.89 f     26.8    0.460
```

# Marginal effects plots

Plot the fitted values for each row

Cylinders held at their mean; assumes front-wheel drive

```
ggplot(predicted_mpg,  
  aes(x = displ, y = .fitted)) +  
  geom_ribbon(aes(ymin = .fitted +  
    (-1.96 * .se.fit),  
    ymax = .fitted +  
    (1.96 * .se.fit)),  
    fill = "#5601A4",  
    alpha = 0.5) +  
  geom_line(size = 1, color = "#5601A4")
```



# Multiple effects at once

We can also move multiple sliders and switches at the same time!

What's the marginal effect of increasing displacement across the front-, rear-, and four-wheel drive cars?

# Multiple effects at once

Create a new dataset with varying displacement *and* varying drive, holding cylinders at its mean

The `expand_grid()` function does this

# Multiple effects at once

```
cars_new_data_fancy <- expand_grid(displ = seq(2, 7, by = 0.1),  
                                  cyl = mean(mpg$cyl),  
                                  drv = c("f", "r", "4"))
```

```
head(cars_new_data_fancy)
```

```
## # A tibble: 6 × 3  
##   displ   cyl drv  
##   <dbl> <dbl> <chr>  
## 1     2   5.89 f  
## 2     2   5.89 r  
## 3     2   5.89 4  
## 4    2.1  5.89 f  
## 5    2.1  5.89 r  
## 6    2.1  5.89 4
```



# Multiple effects at once

Plug each of those rows of data into the model with `augment()`

```
predicted_mpg_fancy <- augment(car_model_big, newdata = cars_new_data_fancy,  
                               se_fit = TRUE)
```

```
head(predicted_mpg_fancy)
```

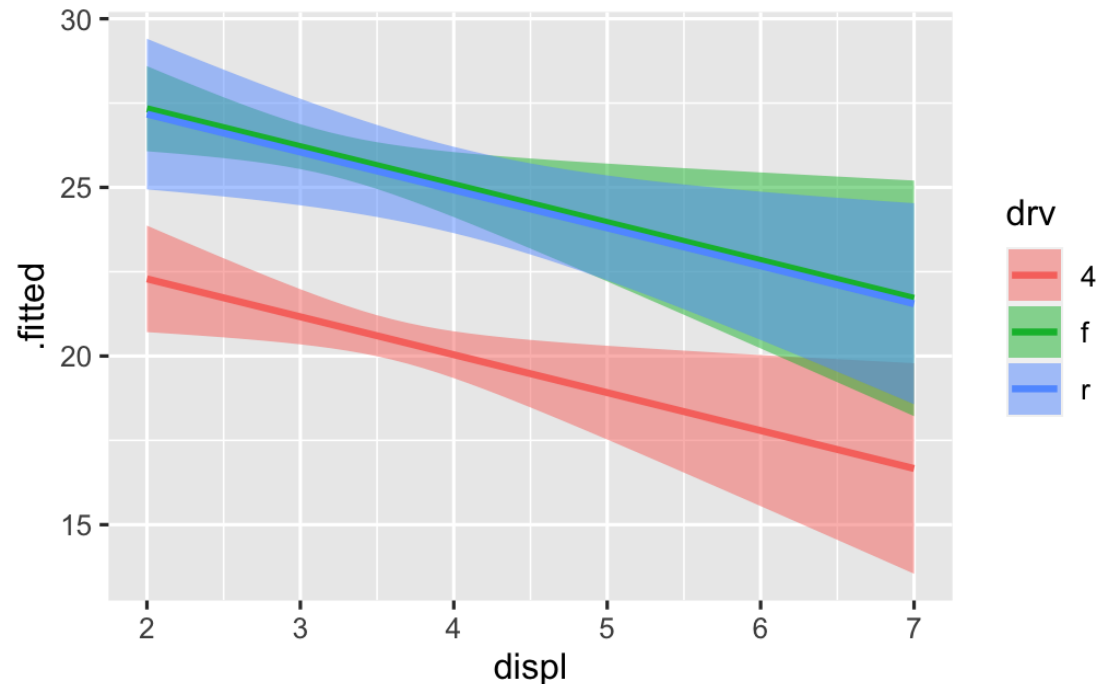
```
## # A tibble: 6 × 5  
##   displ   cyl drv   .fitted .se.fit  
##   <dbl> <dbl> <chr>   <dbl>   <dbl>  
## 1     2     5.89 f       27.3    0.644  
## 2     2     5.89 r       27.2    1.14  
## 3     2     5.89 4       22.3    0.805  
## 4     2.1   5.89 f       27.2    0.604  
## 5     2.1   5.89 r       27.1    1.10  
## 6     2.1   5.89 4       22.2    0.763
```

# Multiple effects at once

Plot the fitted values for each row

Cylinders held at their mean; colored/filled by drive

```
ggplot(predicted_mpg_fancy,  
  aes(x = displ, y = .fitted)) +  
  geom_ribbon(aes(ymin = .fitted +  
    (-1.96 * .se.fit),  
    ymax = .fitted +  
    (1.96 * .se.fit),  
    fill = drv),  
  alpha = 0.5) +  
  geom_line(aes(color = drv), linewidth = 1)
```

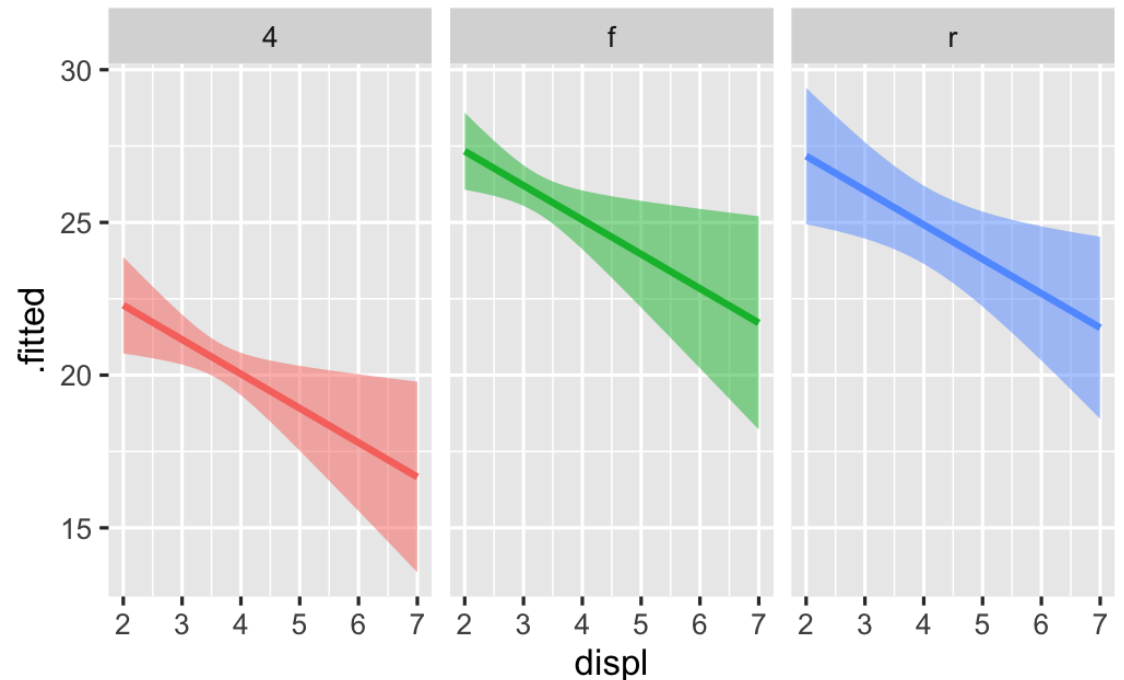


# Multiple effects at once

Plot the fitted values for each row

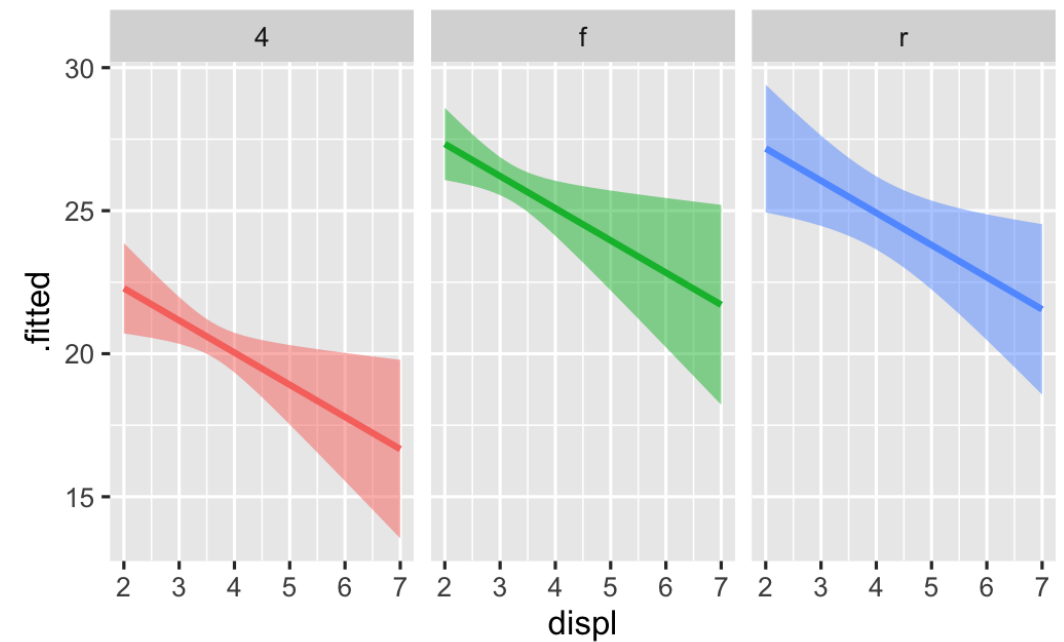
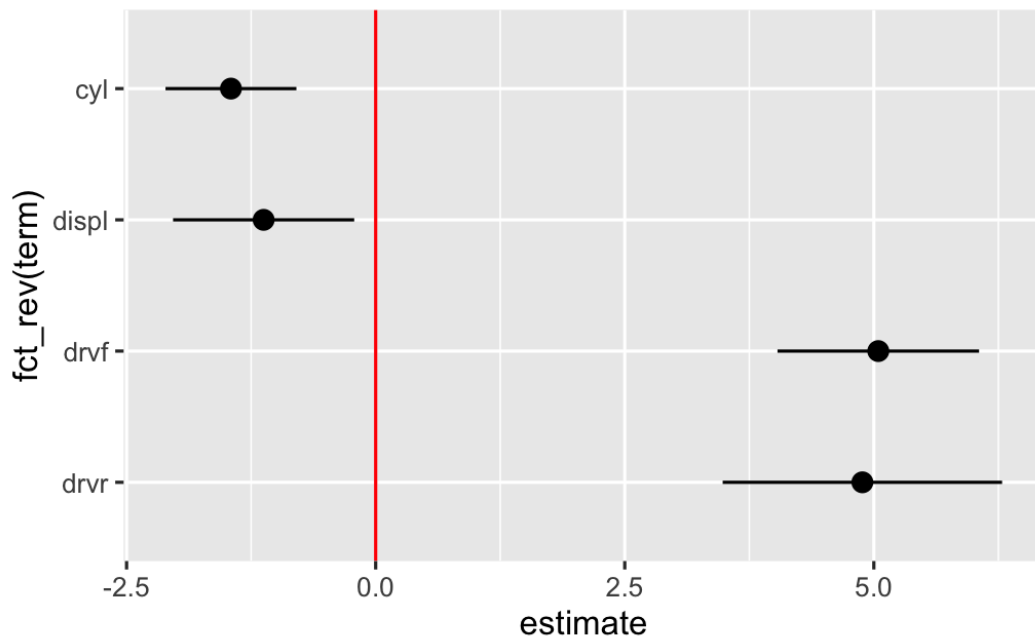
Cylinders held at their mean; colored/filled/faceted by drive

```
ggplot(predicted_mpg_fancy,  
  aes(x = displ, y = .fitted)) +  
  geom_ribbon(aes(ymin = .fitted +  
    (-1.96 * .se.fit),  
    ymax = .fitted +  
    (1.96 * .se.fit),  
    fill = drv),  
  alpha = 0.5) +  
  geom_line(aes(color = drv), linewidth = 1)  
  guides(fill = "none", color = "none") +  
  facet_wrap(vars(drv))
```



# Not just OLS!

These plots are for an OLS model built with  $\tau_m()$



# Any type of statistical model

The same techniques work for pretty much any model R can run

Logistic, probit, and multinomial regression (ordered and unordered)

Multilevel (i.e. mixed and random effects) regression

Bayesian models

(These are extra pretty with the `{tidybayes}` package)

Machine learning models

If it has coefficients and/or if it makes predictions,  
you can (and should) visualize it!