Causal Modeling in R: Whole Game

Malcolm Barrett

RStudio, PBC

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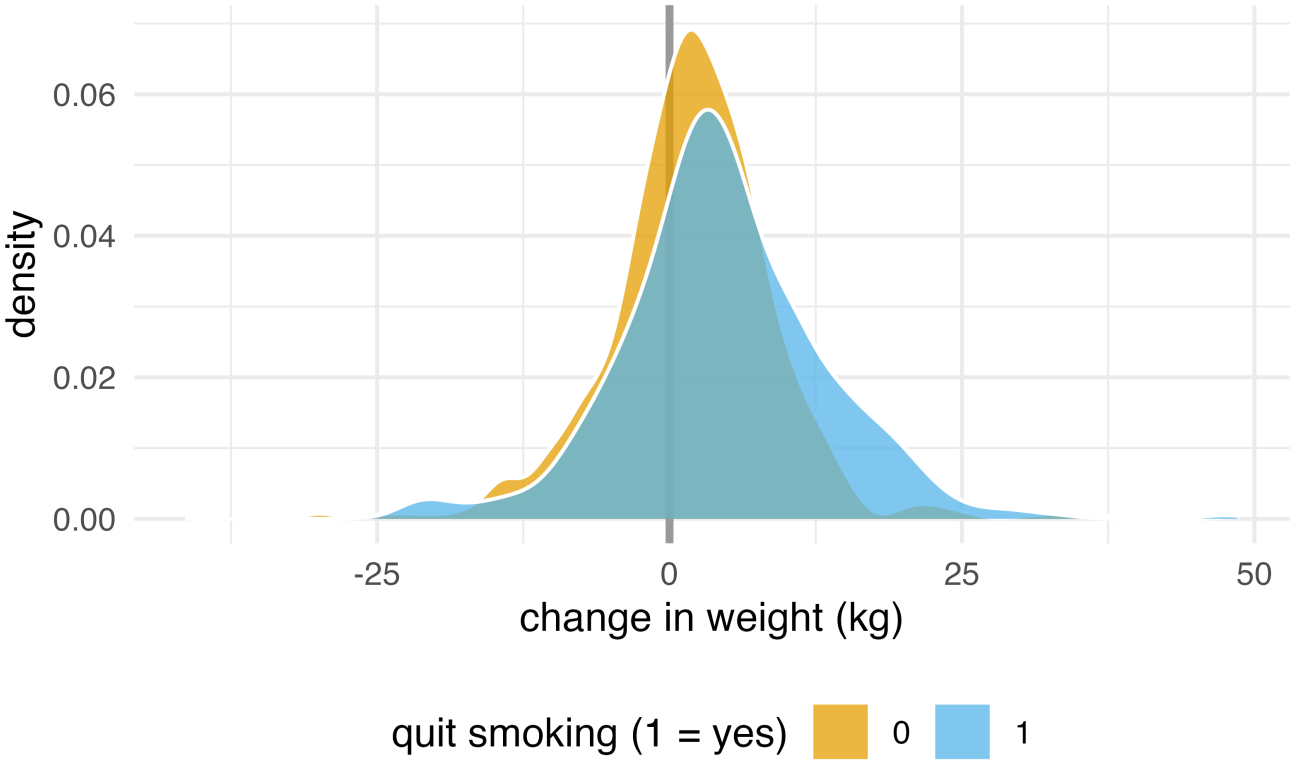
1. **Specify causal question**
2. Draw assumptions (causal diagram)
3. Model assumptions (e.g. propensity score)
4. Analyze propensities (diagnostics)
5. Estimate causal effects (e.g. IPW)
6. Sensitivity analysis (more later!)

Do people who quit smoking gain weight?

```r
library(causaldata)
nhefs_complete_uc <- nhefs_complete %>%
  filter(censored == 0)
nhefs_complete_uc
```

```
## # A tibble: 1,566 × 67
##     seqn  qsmk death yrdth modth dadth   sbp   dbp sex
##    <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <fct>
##  1   233     0     0    NA    NA    NA   175    96 0
##  2   235     0     0    NA    NA    NA   123    80 0
##  3   244     0     0    NA    NA    NA   115    75 1
##  4   245     0     1    85     2    14   148    78 0
##  5   252     0     0    NA    NA    NA   118    77 0
##  6   257     0     0    NA    NA    NA   141    83 1
##  7   262     0     0    NA    NA    NA   132    69 1
##  8   266     0     0    NA    NA    NA   100    53 1
##  9   419     0     1    84    10    13   163    79 0
## 10   420     0     1    86    10    17   184   106 0
## # … with 1,556 more rows, and 58 more variables: age <dbl>,
## #   race <fct>, income <dbl>, marital <dbl>, school <dbl>,
## #   education <fct>, …
```

Did those who quit smoking gain weight?

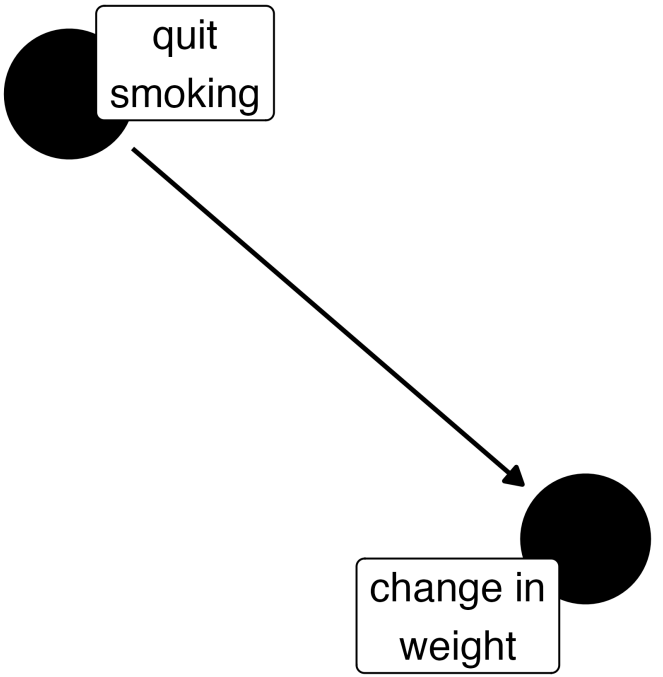


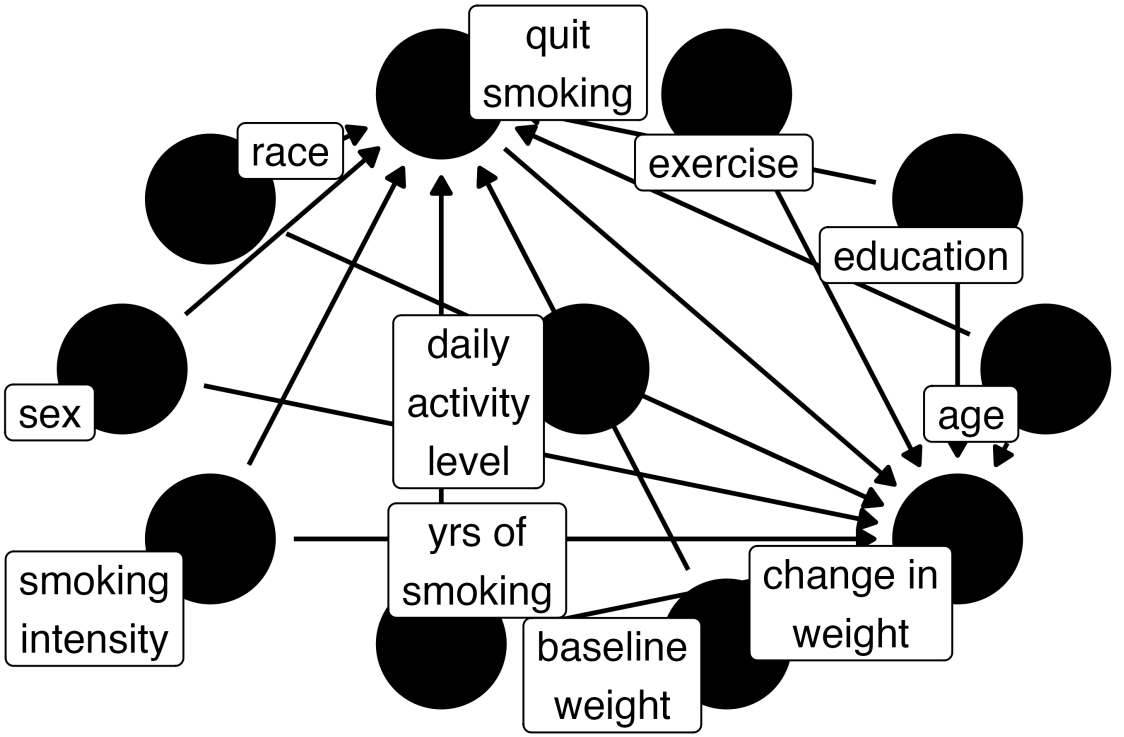
Did those who quit smoking gain weight?

```r
# ~2.5 KGs gained for quit vs. not quit
nhefs_complete_uc %>%
  group_by(qsmk) %>%
  summarize(
    mean_weight_change = mean(wt82_71),
    sd = sd(wt82_71),
    .groups = "drop"
  )
```

```
## # A tibble: 2 × 3
##    qsmk mean_weight_change    sd
##   <dbl>              <dbl> <dbl>
## 1     0               1.98  7.45
## 2     1               4.53  8.75
```

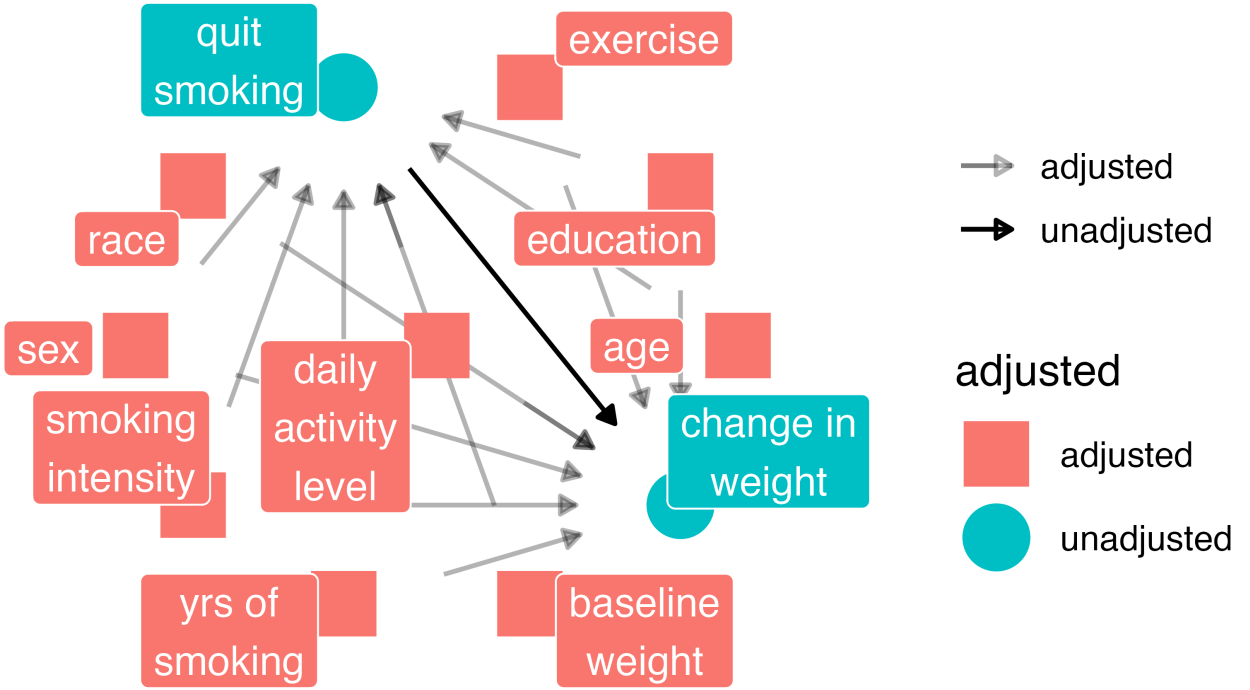
draw your assumptions


quit
smoking
change in
weight


quit smoking
race
exercise
education
daily activity level
sex
age
smoking intensity
yrs of smoking
change in weight
baseline weight

What do I need to control for?

cation, exercise, race, sex, smokeintensity,



Multivariable regression: what's the association?

```
lm(
  wt82_71~ qsmk + sex +
    race + age + I(age^2) + education +
    smokeintensity + I(smokeintensity^2) +
    smokeyrs + I(smokeyrs^2) + exercise + active +
    wt71 + I(wt71^2),
  data = nhefs_complete_uc
) %>%
  tidy(conf.int = TRUE) %>%
  filter(term == "qsmk")
```

Multivariable regression: what's the association?

```
lm(
  wt82_71~ qsmk + sex +
    race + age + I(age^2) + education +
    smokeintensity + I(smokeintensity^2) +
    smokeyrs + I(smokeyrs^2) + exercise + active +
    wt71 + I(wt71^2),
  data = nhefs_complete_uc
) %>%
  tidy(conf.int = TRUE) %>%
  filter(term == "qsmk")
```

```
## # A tibble: 1 × 7
##   term  estimate std.error statistic  p.value conf.low
##   <chr>    <dbl>     <dbl>     <dbl>    <dbl>    <dbl>
## 1 qsmk      3.46     0.438      7.90 5.36e-15     2.60
## # … with 1 more variable: conf.high <dbl>
```

model your assumptions

counterfactual: what if everyone quit smoking vs. what if no one quit smoking

Fit propensity score model

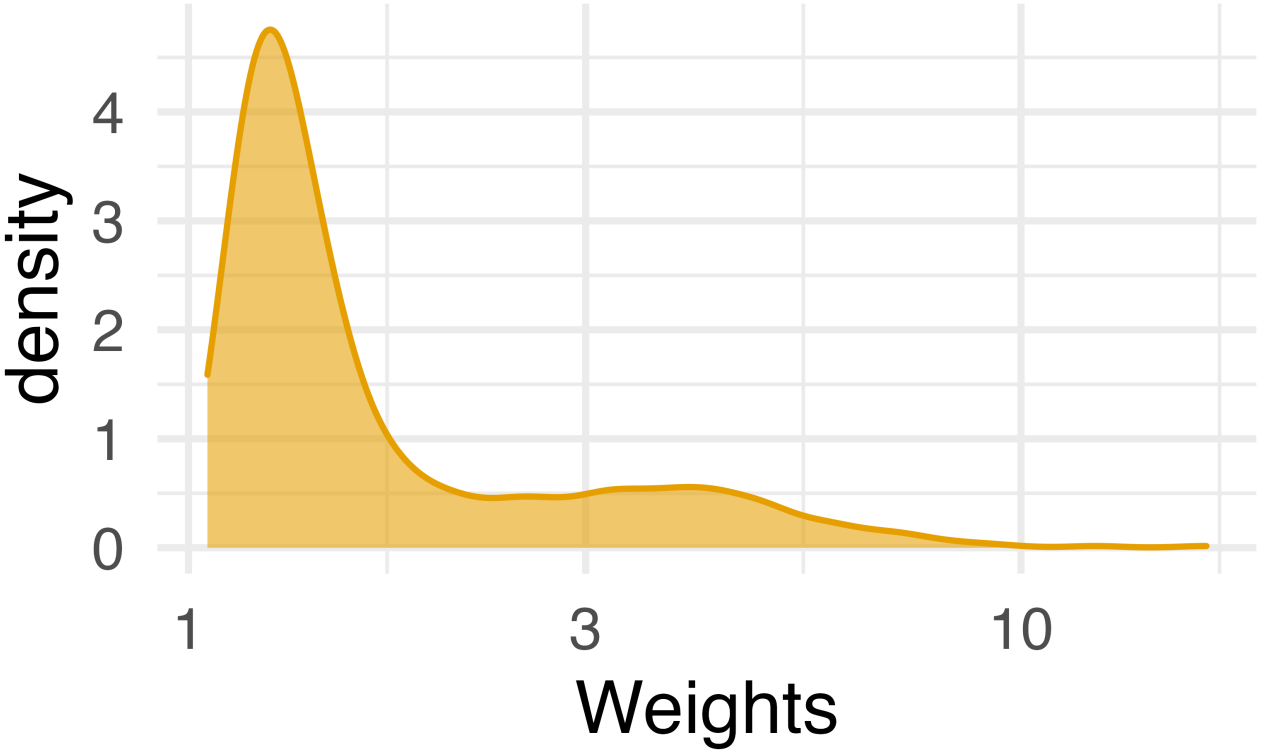
```
propensity_model <- glm(
  qsmk ~ sex +
    race + age + I(age^2) + education +
    smokeintensity + I(smokeintensity^2) +
    smokeyrs + I(smokeyrs^2) + exercise + active +
    wt71 + I(wt71^2),
  family = binomial(),
  data = nhefs_complete_uc
)
```

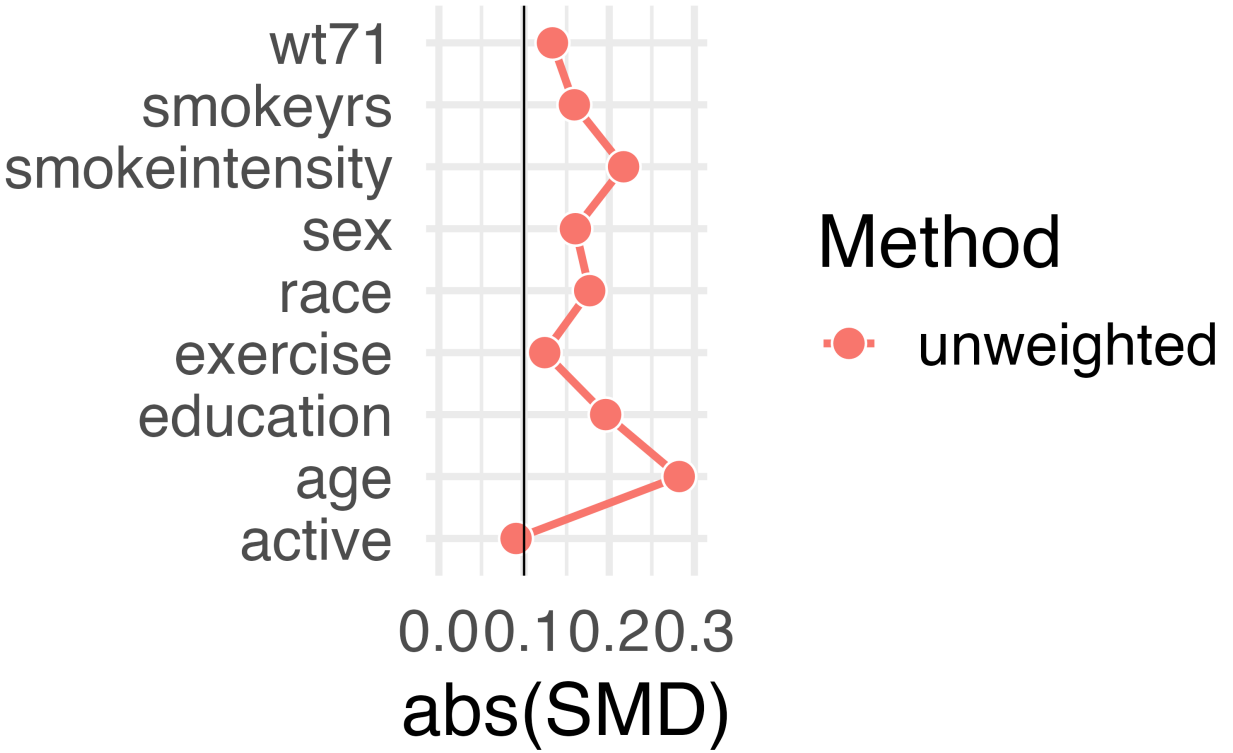
Calculate inverse probability weights

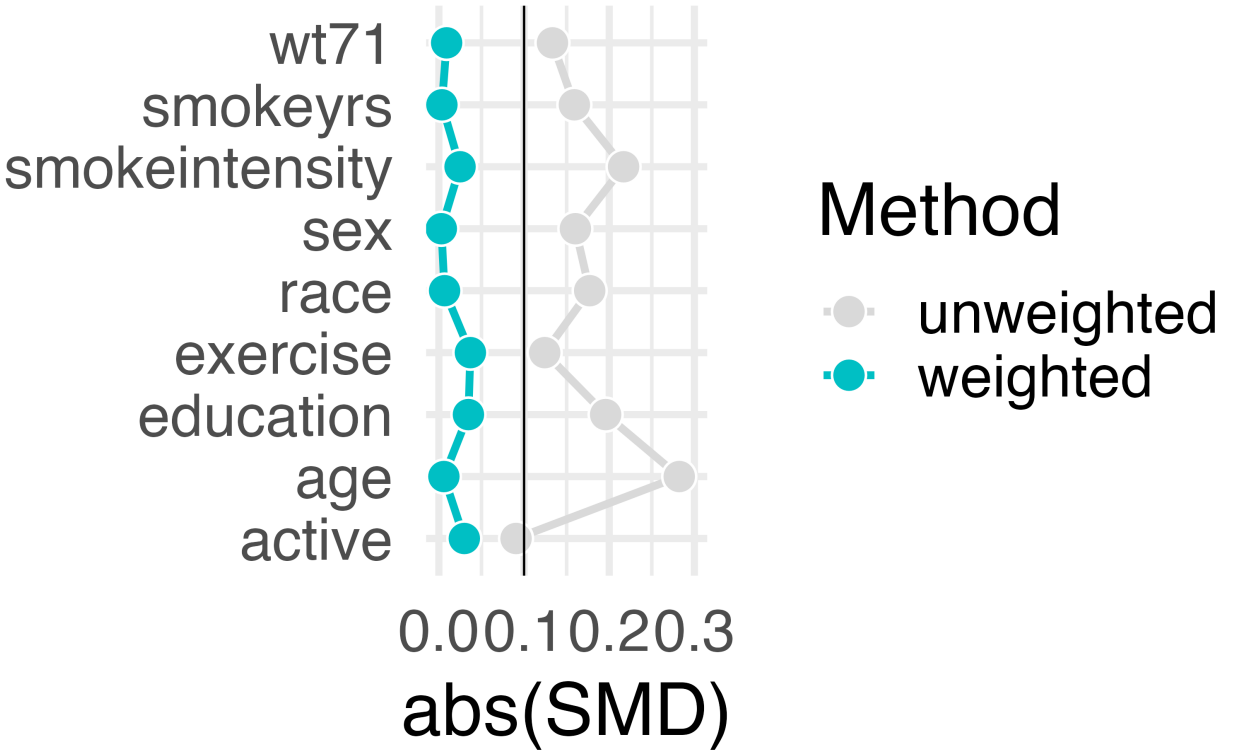
```
nhefs_complete_uc <- propensity_model %>%
  # predict whether quit smoking
  augment(type.predict = "response", data = nhefs_complete_uc) %>%
  # calculate inverse probability
  mutate(wts = 1 / ifelse(qsmk == 0, 1 - .fitted, .fitted))
```

diagnose your model assumptions

What's the distribution of weights?




wt71
smokeyrs
smokeintensity
sex
race
exercise
education
age
active
0.0
0.1
0.2
0.3
abs(SMD)
Method
unweighted


wt71
smokeyrs
smokeintensity
sex
race
exercise
education
age
active
0.0
0.1
0.2
0.3
abs(SMD)
Method
unweighted
weighted

estimate the causal effects

Estimate causal effect with IPW

```
ipw_model <- lm(
  wt82_71 ~ qsmk,
  data = nhefs_complete_uc,
  weights = wts
)

ipw_estimate <- ipw_model %>%
  tidy(conf.int = TRUE) %>%
  filter(term == "qsmk")
```

Estimate causal effect with IPW

```
ipw_estimate
```

```
## # A tibble: 1 × 7
##   term  estimate std.error statistic  p.value conf.low
##   <chr>    <dbl>     <dbl>     <dbl>    <dbl>    <dbl>
## 1 qsmk      3.44     0.408      8.43 7.47e-17     2.64
## # … with 1 more variable: conf.high <dbl>
```

Let's fix our confidence intervals with robust SEs!

```r
# also see robustbase, survey, gee, and others
library(estimatr)
ipw_model_robust <- lm_robust(
  wt82_71 ~ qsmk,
  data = nhefs_complete_uc,
  weights = wts
)

ipw_estimate_robust <- ipw_model_robust %>%
  tidy(conf.int = TRUE) %>%
  filter(term == "qsmk")
```

Let's fix our confidence intervals with robust SEs!

```
as_tibble(ipw_estimate_robust)
```

```
## # A tibble: 1 × 9
##   term  estimate std.error statistic  p.value conf.low
##   <chr>    <dbl>     <dbl>     <dbl>    <dbl>    <dbl>
## 1 qsmk      3.44     0.526      6.54 8.57e-11     2.41
## # … with 3 more variables: conf.high <dbl>, df <dbl>,
## #   outcome <chr>
```

Let's fix our confidence intervals with the bootstrap!

```
# fit ipw model for a single bootstrap sample
fit_ipw_not_quite_rightly <- function(split, ...) {
  # get bootstrapped data sample with `rsample::analysis()`
  .df <- analysis(split)

  # fit ipw model
  lm(wt82_71 ~ qsmk, data = .df, weights = wts) %>%
    tidy()
}
```

```r
fit_ipw <- function(split, ...) {
  .df <- analysis(split)

  # fit propensity score model
  propensity_model <- glm(
    qsmk ~ sex +
      race + age + I(age^2) + education +
      smokeintensity + I(smokeintensity^2) +
      smokeyrs + I(smokeyrs^2) + exercise + active +
      wt71 + I(wt71^2),
    family = binomial(),
    data = .df
  )

  # calculate inverse probability weights
  .df <- propensity_model %>%
    augment(type.predict = "response", data = .df) %>%
    mutate(wts = 1 / ifelse(qsmk == 0, 1 - .fitted, .fitted))

  # fit correctly bootsrapped ipw model
  lm(wt82_71 ~ qsmk, data = .df, weights = wts) %>%
    tidy()
}
```

Using {rsample} to bootstrap our causal effect

```r
# fit ipw model to bootstrapped samples
ipw_results <- bootstraps(nhefs_complete, 1000, apparent = TRUE) %>%
  mutate(results = map(splits, fit_ipw))
```

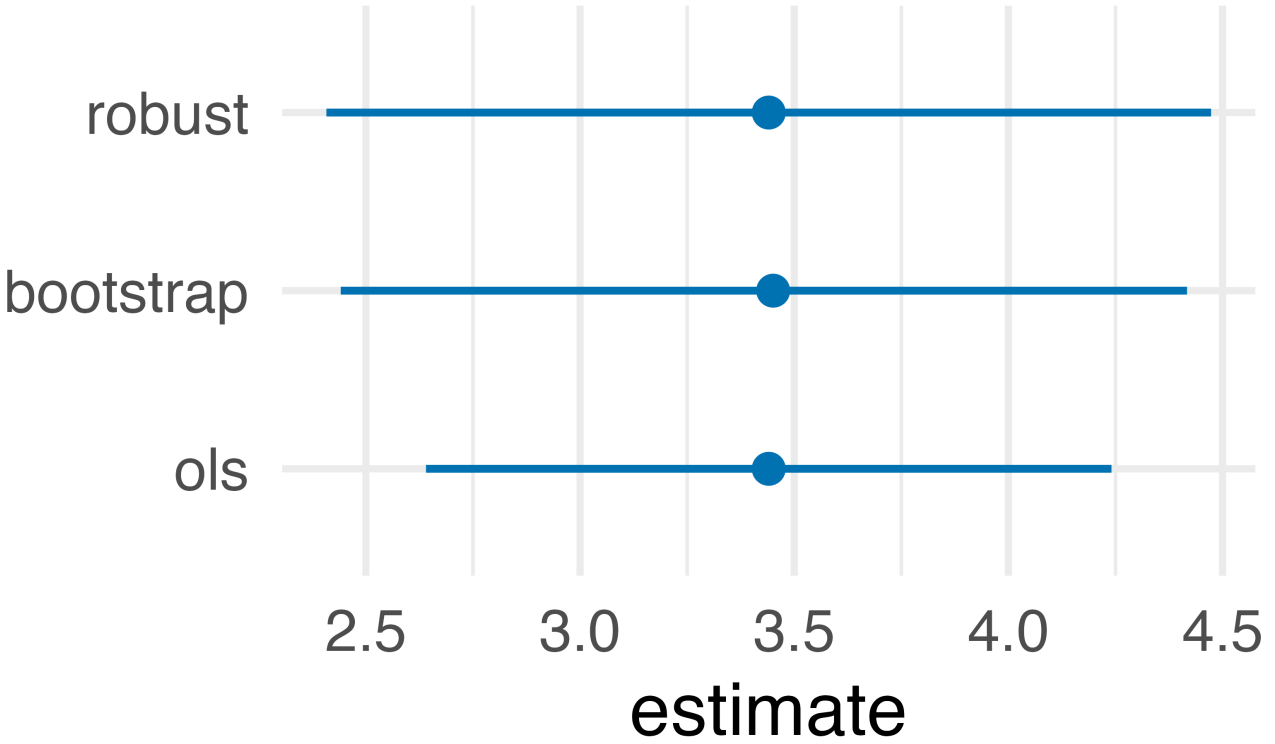
Using {rsample} to bootstrap our causal effect

```
# get t-statistic-based CIs
boot_estimate <- int_t(ipw_results, results) %>%
  filter(term == "qsmk")

boot_estimate
```

Using {rsample} to bootstrap our causal effect

```
# get t-statistic-based CIs
boot_estimate <- int_t(ipw_results, results) %>%
  filter(term == "qsmk")

boot_estimate
```

```
## # A tibble: 1 × 6
##   term  .lower .estimate .upper .alpha .method
##   <chr>  <dbl>     <dbl>  <dbl>  <dbl> <chr>
## 1 qsmk    2.44      3.45   4.42   0.05 student-t
```


robust
bootstrap
ols
2.5
3.0
3.5
4.0
4.5
estimate

Our causal effect estimate: 3.5 kg (95% CI 2.4 kg, 4.4 kg)

Review the R Markdown file... later!

Resources

Causal Inference: Comprehensive text on causal inference. Free online.

Causal Inference Notebook: R code to go along with Causal Inference

Bootstrap confidence intervals with {rsample}