Web Appendix 2: Simulations — Inverse Probability Weights for Quasi-Continuous Ordinal Exposures with a Binary Outcome: Method Comparison and Case Study

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Setup

Generate Data

Generating data per stipulations of Naimi, Moodie, Auger, Kaufman, Epidemiology 2014; 25: 292-299 (1).

To generate the skewed version of `mage`, which we define as `mage_g`, we started with a gamma distribution with shape equal to `0.5` and scale equal to `500`. We then shifted the mean to `0` and changed it from right skewed to left skew (to make it a more appropriate skew for maternal age). We then normalized the standard deviation to `1` so that we could stretch the distribution to have the same standard deviation as `mage`. Finally, we set the mean of `mage_g` to the mean of `mage` and reallocated any `mage_g` values of less than `11` to the mean age. To generate the updated μ, μ_2, we increased the correlation between `mage_g` and μ_2 from `0.025` to `0.25`.

```
# function to generate data per Naimi et al. specifications,
# but make the exposure ordinal instead of continuous via rounding
sim_data <- function(n) {
  # draw maternal age from normal distribution
  mage <- rnorm(n, 29.84, sqrt(21.60))

  # maternal age from gamma distribution for a conditionally normal
  # but marginally not normal covariate
  m1 <- rgamma(n, shape = 0.5, scale = 5000) # make very skewed distribution, sims is 5 and 5
  m2 <- (m1 - mean(m1)) * -1 # shift the mean to zero and
  # flip the direction of the skew (so left instead of right skewed)
  m3 <- m2 / sd(m2) # makes sd 1
  m4 <- m3 * sd(mage) # stretch so it has the sd of mage
  mage_g <- m4 + mean(mage) # make it have the same mean as mage
  mage_g[mage_g < 11] <- mean(mage_g) # make any values < 0 the mean,
  # since maternal age cannot really be under 11

  # draw paternal age from normal distribution
  page <- rnorm(n, 32.52, sqrt(30.45))

  # establish parity with same parameters as Naimi et al.
  parityA <- runif(n)
  parity <- ifelse(parityA <= 0.24, 2,
              ifelse(parityA <= 0.24 + 0.07, 3,
```

```
                      ifelse(parityA <= 0.24 + 0.07 + 0.02, 4,
                             ifelse(parityA <= 0.24 + 0.07 + 0.02 + 0.02, 5, 1))))
parity2 <- ifelse(parity == 2, 1, 0)
parity3 <- ifelse(parity == 3, 1, 0)
parity4 <- ifelse(parity == 4, 1, 0)
parity5 <- ifelse(parity == 5, 1, 0)

# mu w/o strong correlation with maternal age
mu_un <- (0.025 * mage) + (0.0025 * page) + (0.00125 * mage * page) -
(0.21 * parity2) - (0.22 * parity3) - (0.45 * parity4) - (0.45 * parity5)

# mu w/ gamma distributed maternal age and strong correlation
mu_g <- (0.25 * mage_g) + (0.0025 * page) + (0.00125 * mage_g * page) -
(0.21 * parity2) - (0.22 * parity3) - (0.45 * parity4) - (0.45 * parity5)

# normal exposure distribution, but round so it's ordinal to nearest 0.1
x1 <- round(15 + mu_un + rnorm(n, 0, sqrt(2)), 1)

# normal exposure distribution, but marginally not normal, but round so it's ordinal to nearest 0.1
x2 <- round(15 + mu_g + rnorm(n, 0, sqrt(2)), 1)

# poisson exposure distribution, but round so it's ordinal to nearest 0.1
x3 <- round(pmax(rpois(n, mu_un) + rnorm(n,0,1), 0), 1)

# normal exposure distribution, but round so it's ordinal to nearest 1
x4 <- round(15 + mu_un + rnorm(n, 0, sqrt(2)))

# normal exposure distribution, but marginally not normal, but round so it's ordinal to nearest 1
x5 <- round(15 + mu_g + rnorm(n, 0, sqrt(2)))

# poisson exposure distribution, but round so it's ordinal to nearest 1
x6 <- round(pmax(rpois(n, mu_un) + rnorm(n,0,1), 0))

# now replicate Naimi's continuous exposures
n_x1 <- 15 + mu_un + rnorm(n, 0, sqrt(2))
# n_x1 <- rnorm(n, 15 + mu_un, 1.5) #
# <- I think this is how they technically did it, but they are the same.

n_x2 <- pmax(rpois(n, mu_un) + rnorm(n,0,1), 0)

# outcome normal exposure distribution, uncorrelated with maternal age
y1 <- rbinom(n, 1, (1  + exp(-(-11.5 + log(1.25) * x1 + log(1.7) * sqrt(mage) + log(1.5) * sqrt(page)
                      log(0.75) * parity2 + log(0.8) * parity3 + log(0.85) * parity4 + log(0.9) *pari

# normal exposure distribution, but marginally not normal
y2 <- rbinom(n, 1, (1  + exp(-(-13 + log(1.25) * x2 + log(1.7) * sqrt(mage_g) +
                                 log(1.5) * sqrt(page) + log(0.75) * parity2 +
                                 log(0.8) * parity3 + log(0.85) * parity4 +
                                 log(0.9) *parity5)))^(-1))

# outcome poisson exposure distribution, uncorrelated with maternal age
y3 <- rbinom(n, 1, (1 + exp(-(-8.05 + log(1.25) * x3 + log(1.7) * sqrt(mage) +
                                log(1.5) * sqrt(page) + log(0.75) * parity2 +
```

```
                                 log(0.8) * parity3 + log(0.85) * parity4 +
                                 log(0.9) * parity5)))^(-1))

  # outcome normal exposure distribution, uncorrelated with maternal age
  y4 <- rbinom(n, 1, (1  + exp(-(-11.5 + log(1.25) * x4 + log(1.7) * sqrt(mage) + log(1.5) * sqrt(page)
                        log(0.75) * parity2 + log(0.8) * parity3 + log(0.85) * parity4 + log(0.9) *pari

  # normal exposure distribution, but marginally not normal
  y5 <- rbinom(n, 1, (1  + exp(-(-13 + log(1.25) * x5 + log(1.7) * sqrt(mage_g) +
                                  log(1.5) * sqrt(page) + log(0.75) * parity2 +
                                  log(0.8) * parity3 + log(0.85) * parity4 +
                                  log(0.9) *parity5)))^(-1))

  # outcome poisson exposure distribution, uncorrelated with maternal age
  y6 <- rbinom(n, 1, (1 + exp(-(-8.05 + log(1.25) * x6 + log(1.7) * sqrt(mage) +
                                 log(1.5) * sqrt(page) + log(0.75) * parity2 +
                                 log(0.8) * parity3 + log(0.85) * parity4 +
                                 log(0.9) * parity5)))^(-1))

  # replicate Naimi's outcomes given continuous exposures
  n_y1 <- rbinom(n, 1, (1  + exp(-(-11.5 + log(1.25) * n_x1 + log(1.7) * sqrt(mage) +
                                    log(1.5) * sqrt(page) + log(0.75) * parity2 +
                                    log(0.8) * parity3 + log(0.85) * parity4 +
                                    log(0.9) * parity5)))^(-1))

  n_y2 <- rbinom(n, 1, (1 + exp(-(-8.05 + log(1.25) * n_x2 + log(1.7) * sqrt(mage) +
                                   log(1.5) * sqrt(page) + log(0.75) * parity2 +
                                   log(0.8) * parity3 + log(0.85) * parity4 +
                                   log(0.9) * parity5)))^(-1))

  # create df with all covariates as output
  data.frame(mage, mage_g, page, parity2, parity3, parity4, parity5,
             x1, x2, x3, x4, x5, x6, n_x1, n_x2, y1, y2, y3, y4, y5, y6, n_y1, n_y2)
}

# to check outcome prevalence with different intercepts
#table1::table1(~ factor(y1) + factor(y2) + factor(y3) + factor(y4) + factor(y5) + factor(y6), data = s

# test exposure distributions
# test <- sim_data(n = 30000)
# hist(test$x1)
# hist(test$x2)
# hist(test$x3)
# hist(test$x4)
# hist(test$x5)
# hist(test$x6)
```

Simulations

Do 3000 simulations and generate weights for each simulation, combine each simulation into one long dataframe with weights and list and simulation number. Generate weights with OLS, CBGPS, QB10, QB15, QB20, and CPM.

For X_2, we updated the intercept values (from -11.5 [X_1] to -11.4 [X_2]) to maintain a marginal probability of the outcome of approximately 0.08 with the updated exposure distributions.

We calculated the sIPW denominators using the following regression formula per Naimi et al.'s specifications, where C are the selected confounders, with *mage_g* instead of *mage* when i ϵ {2} and binned exposures instead of X_i when calculating QB weights:

$E(X_i \mid C) = \beta_1(\text{mage}) + \beta_2(\text{page}) + \beta_3(\text{mage*page}) + \beta_4(\text{parity2}) + \beta_5(\text{parity3}) + \beta_6(\text{parity4}) + \beta_7(\text{parity5})$

The range, median, and mean of the exposure distributions are in Supplemental Table 1.2.

```
# register clusters (use 7 cores)
registerDoParallel(detectCores() - 1)

# number of reps (will go up to 3000, can tinker to test things)
n = 3000

# now generate weights
# (will generate weights in each simulated dataset individually)
sims <- foreach(i = 1:n, .inorder = FALSE, .errorhandling = "remove") %dopar% {
  # first need to generate data and quantile binned exposures
  df <- sim_data(n = 1500) %>%
  mutate(x1_qb10 = as.numeric(cut2(x1, g = 10)),
         x2_qb10 = as.numeric(cut2(x2, g = 10)),
         x3_qb10 = as.numeric(cut2(x3, g = 10)),
         x4_qb10 = as.numeric(cut2(x4, g = 10)),
         x1_qb15 = as.numeric(cut2(x1, g = 15)),
         x2_qb15 = as.numeric(cut2(x2, g = 15)),
         x3_qb15 = as.numeric(cut2(x3, g = 15)),
         x4_qb15 = as.numeric(cut2(x4, g = 15)),
         x1_qb20 = as.numeric(cut2(x1, g = 20)),
         x2_qb20 = as.numeric(cut2(x2, g = 20)),
         x3_qb20 = as.numeric(cut2(x3, g = 20)),
         x4_qb20 = as.numeric(cut2(x4, g = 20)))

  # start by creating formulas
  x1_formula <- formula(x1 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)
  x2_formula <- formula(x2 ~ mage_g + page + mage_g*page + parity2 + parity3 + parity4 + parity5)
  x3_formula <- formula(x3 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)
  x4_formula <- formula(x4 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)
  x5_formula <- formula(x5 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)
  x6_formula <- formula(x6 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)

  # use WeightIt package to generate OLS and CBGPS weights

  # OLS
  x1_ols_wts <- weightit(x1_formula, df %>% filter(!is.na(x1)), method = "ps")$weights
  x2_ols_wts <- weightit(x2_formula, df %>% filter(!is.na(x2)), method = "ps")$weights
  x3_ols_wts <- weightit(x3_formula, df %>% filter(!is.na(x3)), method = "ps")$weights
  x4_ols_wts <- weightit(x4_formula, df %>% filter(!is.na(x4)), method = "ps")$weights
  x5_ols_wts <- weightit(x5_formula, df %>% filter(!is.na(x5)), method = "ps")$weights
  x6_ols_wts <- weightit(x6_formula, df %>% filter(!is.na(x6)), method = "ps")$weights

  #CBGPS
  x1_cbgps_wts <- weightit(x1_formula, df %>% filter(!is.na(x1)), method = "cbps",
                           over = FALSE)$weights
```

```
x2_cbgps_wts <- weightit(x2_formula, df %>% filter(!is.na(x2)), method = "cbps",
                          over = FALSE)$weights
x3_cbgps_wts <- weightit(x3_formula, df %>% filter(!is.na(x3)), method = "cbps",
                          over = FALSE)$weights
x4_cbgps_wts <- weightit(x4_formula, df %>% filter(!is.na(x4)), method = "cbps",
                          over = FALSE)$weights
x5_cbgps_wts <- weightit(x5_formula, df %>% filter(!is.na(x5)), method = "cbps",
                          over = FALSE)$weights
x6_cbgps_wts <- weightit(x6_formula, df %>% filter(!is.na(x6)), method = "cbps",
                          over = FALSE)$weights

#npCBGPS
x1_npcbgps_wts <- weightit(x1_formula, df %>% filter(!is.na(x1)), method = "npcbps",
                          over = FALSE)$weights
x2_npcbgps_wts <- weightit(x2_formula, df %>% filter(!is.na(x2)), method = "npcbps",
                          over = FALSE)$weights
x3_npcbgps_wts <- weightit(x3_formula, df %>% filter(!is.na(x3)), method = "npcbps",
                          over = FALSE)$weights
x4_npcbgps_wts <- weightit(x4_formula, df %>% filter(!is.na(x4)), method = "npcbps",
                          over = FALSE)$weights
x5_npcbgps_wts <- weightit(x5_formula, df %>% filter(!is.na(x5)), method = "npcbps",
                          over = FALSE)$weights
x6_npcbgps_wts <- weightit(x6_formula, df %>% filter(!is.na(x6)), method = "npcbps",
                          over = FALSE)$weights

# use orm.wt file to create quantile binning and OLR weights


# only doing QB for x1-x3, because at smaller number of categories, they are the same thing
# QB10
x1_qb10_wts <- orm.wt(object = df %>% filter(!is.na(x1)),
                  exposure = "x1_qb10",
                  cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                  parity5") %>%
  unlist()
x2_qb10_wts <- orm.wt(object = df %>% filter(!is.na(x2)),
                  exposure = "x2_qb10",
                  cov_form = "~ mage_g + page + mage_g*page + parity2 + parity3 + parity4 +
                  parity5") %>%
  unlist()
x3_qb10_wts <- orm.wt(object = df %>% filter(!is.na(x3)),
                  exposure = "x3_qb10",
                  cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                  parity5") %>%
  unlist()

# QB15
x1_qb15_wts <- orm.wt(object = df %>% filter(!is.na(x1)),
                  exposure = "x1_qb15",
                  cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                  parity5") %>%
  unlist()
x2_qb15_wts <- orm.wt(object = df %>% filter(!is.na(x2)),
```

```
                    exposure = "x2_qb15",
                    cov_form = "~ mage_g + page + mage_g*page + parity2 + parity3 + parity4 +
                    parity5") %>%
  unlist()
x3_qb15_wts <- orm.wt(object = df %>% filter(!is.na(x3)),
                    exposure = "x3_qb15",
                    cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                    parity5") %>%
  unlist()

# QB20
x1_qb20_wts <- orm.wt(object = df %>% filter(!is.na(x1)),
                    exposure = "x1_qb20",
                    cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                    parity5") %>%
  unlist()
x2_qb20_wts <- orm.wt(object = df %>% filter(!is.na(x2)),
                    exposure = "x2_qb20",
                    cov_form = "~ mage_g + page + mage_g*page + parity2 + parity3 + parity4 +
                    parity5") %>%
  unlist()
x3_qb20_wts <- orm.wt(object = df %>% filter(!is.na(x3)),
                    exposure = "x3_qb20",
                    cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                    parity5") %>%
  unlist()

# OLR
x1_olr_wts <- orm.wt(object = df %>% filter(!is.na(x1)),
                    exposure = "x1",
                    cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                    parity5") %>%
  unlist()
x2_olr_wts <- orm.wt(object = df %>% filter(!is.na(x2)),
                    exposure = "x2",
                    cov_form = "~ mage_g + page + mage_g*page + parity2 + parity3 + parity4 +
                    parity5") %>%
  unlist()
x3_olr_wts <- orm.wt(object = df %>% filter(!is.na(x3)),
                    exposure = "x3",
                    cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                    parity5") %>%
  unlist()
x4_olr_wts <- orm.wt(object = df %>% filter(!is.na(x4)),
                    exposure = "x4",
                    cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                    parity5") %>%
  unlist()
x5_olr_wts <- orm.wt(object = df %>% filter(!is.na(x5)),
                    exposure = "x5",
                    cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                    parity5") %>%
  unlist()
```

```r
  x6_olr_wts <- orm.wt(object = df %>% filter(!is.na(x6)),
                       exposure = "x6",
                       cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                       parity5") %>%
    unlist()

  # create final dataframe
  data <- data.frame(i, df,
                     x1_ols_wts, x2_ols_wts, x3_ols_wts, x4_ols_wts, x5_ols_wts, x6_ols_wts,
                     x1_cbgps_wts, x2_cbgps_wts, x3_cbgps_wts, x4_cbgps_wts, x5_cbgps_wts, x6_cbgps_wts
                     x1_npcbgps_wts, x2_npcbgps_wts, x3_npcbgps_wts, x4_npcbgps_wts, x5_npcbgps_wts, x6_
                     x1_qb10_wts, x2_qb10_wts, x3_qb10_wts,
                     x1_qb15_wts, x2_qb15_wts, x3_qb15_wts,
                     x1_qb20_wts, x2_qb20_wts, x3_qb20_wts,
                     x1_olr_wts, x2_olr_wts, x3_olr_wts, x4_olr_wts, x5_olr_wts, x6_olr_wts)
}

# add in simluation for anything less than 3000, with new seed across all all streams for parallel proc
set.seed(11111, kind = "L'Ecuyer-CMRG")
n_extra <- 3000 - length(sims)
sims2 <- foreach(i = 1:n_extra, .inorder = FALSE, .errorhandling = "remove") %dopar% {
  # first need to generate data and quantile binned exposures
  df <- sim_data(n = 1500) %>%
  mutate(x1_qb10 = as.numeric(cut2(x1, g = 10)),
         x2_qb10 = as.numeric(cut2(x2, g = 10)),
         x3_qb10 = as.numeric(cut2(x3, g = 10)),
         x4_qb10 = as.numeric(cut2(x4, g = 10)),
         x1_qb15 = as.numeric(cut2(x1, g = 15)),
         x2_qb15 = as.numeric(cut2(x2, g = 15)),
         x3_qb15 = as.numeric(cut2(x3, g = 15)),
         x4_qb15 = as.numeric(cut2(x4, g = 15)),
         x1_qb20 = as.numeric(cut2(x1, g = 20)),
         x2_qb20 = as.numeric(cut2(x2, g = 20)),
         x3_qb20 = as.numeric(cut2(x3, g = 20)),
         x4_qb20 = as.numeric(cut2(x4, g = 20)))

  # start by creating formulas
  x1_formula <- formula(x1 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)
  x2_formula <- formula(x2 ~ mage_g + page + mage_g*page + parity2 + parity3 + parity4 + parity5)
  x3_formula <- formula(x3 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)
  x4_formula <- formula(x4 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)
  x5_formula <- formula(x5 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)
  x6_formula <- formula(x6 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)

  # use WeightIt package to generate OLS and CBGPS weights

  # OLS
  x1_ols_wts <- weightit(x1_formula, df %>% filter(!is.na(x1)), method = "ps")$weights
  x2_ols_wts <- weightit(x2_formula, df %>% filter(!is.na(x2)), method = "ps")$weights
  x3_ols_wts <- weightit(x3_formula, df %>% filter(!is.na(x3)), method = "ps")$weights
  x4_ols_wts <- weightit(x4_formula, df %>% filter(!is.na(x4)), method = "ps")$weights
  x5_ols_wts <- weightit(x5_formula, df %>% filter(!is.na(x5)), method = "ps")$weights
  x6_ols_wts <- weightit(x6_formula, df %>% filter(!is.na(x6)), method = "ps")$weights
```

```
#CBGPS
x1_cbgps_wts <- weightit(x1_formula, df %>% filter(!is.na(x1)), method = "cbps",
                         over = FALSE)$weights
x2_cbgps_wts <- weightit(x2_formula, df %>% filter(!is.na(x2)), method = "cbps",
                         over = FALSE)$weights
x3_cbgps_wts <- weightit(x3_formula, df %>% filter(!is.na(x3)), method = "cbps",
                         over = FALSE)$weights
x4_cbgps_wts <- weightit(x4_formula, df %>% filter(!is.na(x4)), method = "cbps",
                         over = FALSE)$weights
x5_cbgps_wts <- weightit(x5_formula, df %>% filter(!is.na(x5)), method = "cbps",
                         over = FALSE)$weights
x6_cbgps_wts <- weightit(x6_formula, df %>% filter(!is.na(x6)), method = "cbps",
                         over = FALSE)$weights

#npCBGPS
x1_npcbgps_wts <- weightit(x1_formula, df %>% filter(!is.na(x1)), method = "npcbps",
                         over = FALSE)$weights
x2_npcbgps_wts <- weightit(x2_formula, df %>% filter(!is.na(x2)), method = "npcbps",
                         over = FALSE)$weights
x3_npcbgps_wts <- weightit(x3_formula, df %>% filter(!is.na(x3)), method = "npcbps",
                         over = FALSE)$weights
x4_npcbgps_wts <- weightit(x4_formula, df %>% filter(!is.na(x4)), method = "npcbps",
                         over = FALSE)$weights
x5_npcbgps_wts <- weightit(x5_formula, df %>% filter(!is.na(x5)), method = "npcbps",
                         over = FALSE)$weights
x6_npcbgps_wts <- weightit(x6_formula, df %>% filter(!is.na(x6)), method = "npcbps",
                         over = FALSE)$weights

# use orm.wt file to create quantile binning and OLR weights


# only doing QB for x1-x3, because at smaller number of categories, they are the same thing
# QB10
x1_qb10_wts <- orm.wt(object = df %>% filter(!is.na(x1)),
                  exposure = "x1_qb10",
                  cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                  parity5") %>%
  unlist()
x2_qb10_wts <- orm.wt(object = df %>% filter(!is.na(x2)),
                  exposure = "x2_qb10",
                  cov_form = "~ mage_g + page + mage_g*page + parity2 + parity3 + parity4 +
                  parity5") %>%
  unlist()
x3_qb10_wts <- orm.wt(object = df %>% filter(!is.na(x3)),
                  exposure = "x3_qb10",
                  cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                  parity5") %>%
  unlist()

# QB15
x1_qb15_wts <- orm.wt(object = df %>% filter(!is.na(x1)),
                  exposure = "x1_qb15",
                  cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
```

```
                  parity5") %>%
  unlist()
x2_qb15_wts <- orm.wt(object = df %>% filter(!is.na(x2)),
                  exposure = "x2_qb15",
                  cov_form = "~ mage_g + page + mage_g*page + parity2 + parity3 + parity4 +
                  parity5") %>%
  unlist()
x3_qb15_wts <- orm.wt(object = df %>% filter(!is.na(x3)),
                  exposure = "x3_qb15",
                  cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                  parity5") %>%
  unlist()

# QB20
x1_qb20_wts <- orm.wt(object = df %>% filter(!is.na(x1)),
                  exposure = "x1_qb20",
                  cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                  parity5") %>%
  unlist()
x2_qb20_wts <- orm.wt(object = df %>% filter(!is.na(x2)),
                  exposure = "x2_qb20",
                  cov_form = "~ mage_g + page + mage_g*page + parity2 + parity3 + parity4 +
                  parity5") %>%
  unlist()
x3_qb20_wts <- orm.wt(object = df %>% filter(!is.na(x3)),
                  exposure = "x3_qb20",
                  cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                  parity5") %>%
  unlist()

# OLR
x1_olr_wts <- orm.wt(object = df %>% filter(!is.na(x1)),
                  exposure = "x1",
                  cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                  parity5") %>%
  unlist()
x2_olr_wts <- orm.wt(object = df %>% filter(!is.na(x2)),
                  exposure = "x2",
                  cov_form = "~ mage_g + page + mage_g*page + parity2 + parity3 + parity4 +
                  parity5") %>%
  unlist()
x3_olr_wts <- orm.wt(object = df %>% filter(!is.na(x3)),
                  exposure = "x3",
                  cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                  parity5") %>%
  unlist()
x4_olr_wts <- orm.wt(object = df %>% filter(!is.na(x4)),
                  exposure = "x4",
                  cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                  parity5") %>%
  unlist()
x5_olr_wts <- orm.wt(object = df %>% filter(!is.na(x5)),
                  exposure = "x5",
```

```
                      cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                      parity5") %>%
    unlist()
  x6_olr_wts <- orm.wt(object = df %>% filter(!is.na(x6)),
                      exposure = "x6",
                      cov_form = "~ mage + page + mage*page + parity2 + parity3 + parity4 +
                      parity5") %>%
    unlist()

  # create final dataframe
  data <- data.frame(i, df,
                       x1_ols_wts, x2_ols_wts, x3_ols_wts, x4_ols_wts, x5_ols_wts, x6_ols_wts,
                       x1_cbgps_wts, x2_cbgps_wts, x3_cbgps_wts, x4_cbgps_wts, x5_cbgps_wts, x6_cbgps_wts
                       x1_npcbgps_wts, x2_npcbgps_wts, x3_npcbgps_wts, x4_npcbgps_wts, x5_npcbgps_wts, x6
                       x1_qb10_wts, x2_qb10_wts, x3_qb10_wts,
                       x1_qb15_wts, x2_qb15_wts, x3_qb15_wts,
                       x1_qb20_wts, x2_qb20_wts, x3_qb20_wts,
                       x1_olr_wts, x2_olr_wts, x3_olr_wts, x4_olr_wts, x5_olr_wts, x6_olr_wts)
}

# combine
sims <- append(sims, sims2)

# save simulation output
Save(sims)
```

```
# load simulation data
Load(sims)

# make it a dataframe
df <- sims %>% bind_rows(.id = "i")

# create a new dataset with 4.5 million rows to simulate the truth
set.seed(1111)
df_msm_sim <- sim_data(n = nrow(df))
```

```
# Marginal Structural Model "Truth"
getMeanProb_MSM <- function(dat, val, xnum) {
    # returns the mean outcome probability (that is, an estimate of E[Y(t)]) at exposure value [val]
    if (xnum == "x1" | xnum == "x4") {
        alpha <- -11.5
        magevar <- "mage"
    } else if (xnum == "x2" | xnum == "x5") {
        alpha <- -13
        magevar <- "mage_g"
    } else if (xnum == "x3" | xnum == "x6") {
        alpha <- -8.05
        magevar <- "mage"
    }

    lp <-
        alpha +
        log(1.25) * (val) +
        log(1.7) * sqrt(dat[[magevar]])+
```

```r
        log(1.5) * sqrt(dat$page) +
        log(0.75) * dat$parity2 +
        log(0.8) * dat$parity3 +
        log(0.85) * dat$parity4 +
        log(0.9) * dat$parity5
    prob <- plogis(lp)
    mean(prob)
}

# run it with parallel processing

# register clusters (use 6 cores because 6 processes)
registerDoParallel(6)

# now generate weights
msm_truths <- foreach(i = 1:6, .inorder = FALSE, .errorhandling = "remove") %dopar% {
  #exposures
  exps <- c("x1", "x2", "x3", "x4", "x5", "x6")

  # each is a vector of estimates of E[Y(t)]'s: one for each unique t in the original dataset
  # (excluding repeats)
  probs <- lapply(unique(df_msm_sim[[exps[i]]]),
                  function(x) getMeanProb_MSM(df_msm_sim, x, xnum = exps[i]))
}

# save it
Save(msm_truths)
```

```r
# pull in MSM truth, because it  will be too big to run each time
Load(msm_truths)
x1_truth_key <- tibble(x1 = unique(df_msm_sim$x1), prob_x1 = unlist(msm_truths[1]))
x2_truth_key <- tibble(x2 = unique(df_msm_sim$x2), prob_x2 = unlist(msm_truths[2]))
x3_truth_key <- tibble(x3 = unique(df_msm_sim$x3), prob_x3 = unlist(msm_truths[3]))
x4_truth_key <- tibble(x4 = unique(df_msm_sim$x4), prob_x4 = unlist(msm_truths[4]))
x5_truth_key <- tibble(x5 = unique(df_msm_sim$x5), prob_x5 = unlist(msm_truths[5]))
x6_truth_key <- tibble(x6 = unique(df_msm_sim$x6), prob_x6 = unlist(msm_truths[6]))

# now need to link truths with exposure they match
x_truths <- df_msm_sim %>%
  select(x1, x2, x3, x4, x5, x6)

# put in truths
x_truths <- left_join(x_truths, x1_truth_key, by = "x1")
x_truths <- left_join(x_truths, x2_truth_key, by = "x2")
x_truths <- left_join(x_truths, x3_truth_key, by = "x3")
x_truths <- left_join(x_truths, x4_truth_key, by = "x4")
x_truths <- left_join(x_truths, x5_truth_key, by = "x5")
x_truths <- left_join(x_truths, x6_truth_key, by = "x6")

# show that there are no non-missing values of prob_x1:prob_x6 after joining
sum(is.na(x_truths$prob_x1), is.na(x_truths$prob_x2), is.na(x_truths$prob_x3),
    is.na(x_truths$prob_x4), is.na(x_truths$prob_x5), is.na(x_truths$prob_x6))
```

```
[1] 0
```

```r
sum(!is.na(x_truths$prob_x1), !is.na(x_truths$prob_x2), !is.na(x_truths$prob_x3),
    !is.na(x_truths$prob_x4), !is.na(x_truths$prob_x5), !is.na(x_truths$prob_x6))/6
```

```
[1] 4500000
```

```r
# Our MSM: logit{E[Y(t)]}= b0 + b1*t
#      The warning is OK!
msm_x1 <- glm(x_truths$prob_x1 ~ x_truths$x1, family= binomial)
```

```r
true_x1 <- coef(msm_x1)["x_truths$x1"] %>% unname()

msm_x2 <- glm(x_truths$prob_x2 ~ x_truths$x2, family= binomial)
```

```r
true_x2 <- coef(msm_x2)["x_truths$x2"] %>% unname()

msm_x3 <- glm(x_truths$prob_x3 ~ x_truths$x3, family= binomial)
```

```r
true_x3 <- coef(msm_x3)["x_truths$x3"] %>% unname()

msm_x4 <- glm(x_truths$prob_x4 ~ x_truths$x4, family= binomial)
```

```r
true_x4 <- coef(msm_x4)["x_truths$x4"] %>% unname()

msm_x5 <- glm(x_truths$prob_x5 ~ x_truths$x5, family= binomial)
```

```r
true_x5 <- coef(msm_x5)["x_truths$x5"] %>% unname()

msm_x6 <- glm(x_truths$prob_x6 ~ x_truths$x6, family= binomial)
```

```r
true_x6 <- coef(msm_x6)["x_truths$x6"] %>% unname()

# Austin, 2018 approach to finding the truth
# find the true probability, across all 4.5 million observations at each decile (seq(0.1, 0.9, 0.1))
# the the expected probabilities are found below in the bias chunk
getMeanProb <- function(dat, val, xnum) {
    if (xnum == 1 | xnum == 4) {
        alpha <- -11.5
        magevar <- "mage"
    } else if (xnum == 2 | xnum == 5) {
        alpha <- -13
        magevar <- "mage_g"
    } else if (xnum == 3 | xnum == 6) {
        alpha <- -8.05
        magevar <- "mage"
    }
    lp <- alpha +
        log(1.25) * (val) +
        log(1.7) * sqrt(dat[[magevar]])+
        log(1.5) * sqrt(dat$page) +
        log(0.75) * dat$parity2 +
        log(0.8) * dat$parity3 +
        log(0.85) * dat$parity4 +
        log(0.9) * dat$parity5
    # p = (1 + 1/odds)^(-1)
    prob <- (1 + 1/exp(lp))^(-1)
```

```
    mean(prob)
}

# x1
true2_x1_qs <- map_dbl(seq(0.1, 0.9, 0.1), ~ getMeanProb(dat = df_msm_sim,
                                                         val = quantile(df_msm_sim$x1, .x), xnum = 1))

# x2
true2_x2_qs <- map_dbl(seq(0.1, 0.9, 0.1), ~ getMeanProb(dat = df_msm_sim,
                                                         val = quantile(df_msm_sim$x2, .x), xnum = 2))

# x3
true2_x3_qs <- map_dbl(seq(0.1, 0.9, 0.1), ~ getMeanProb(dat = df_msm_sim,
                                                         val = quantile(df_msm_sim$x3, .x), xnum = 3))

# x4
true2_x4_qs <- map_dbl(seq(0.1, 0.9, 0.1), ~ getMeanProb(dat = df_msm_sim,
                                                         val = quantile(df_msm_sim$x4, .x), xnum = 4))

# x5
true2_x5_qs <- map_dbl(seq(0.1, 0.9, 0.1), ~ getMeanProb(dat = df_msm_sim,
                                                         val = quantile(df_msm_sim$x5, .x), xnum = 5))

# x6
true2_x6_qs <- map_dbl(seq(0.1, 0.9, 0.1), ~ getMeanProb(dat = df_msm_sim,
                                                         val = quantile(df_msm_sim$x6, .x), xnum = 6))
```

Web Table 1 - Updated Exposure Levels

```
# get number of exposure levels across simulations
exp_levels <- function(data) {
  x1 <- n_distinct(data$x1)
  x2 <- n_distinct(data$x2)
  x3 <- n_distinct(data$x3)
  x4 <- n_distinct(data$x4)
  x5 <- n_distinct(data$x5)
  x6 <- n_distinct(data$x6)

  data.frame(x1, x2, x3, x4, x5, x6)
}

suptab2 <- map_df(sims, ~ exp_levels(.x)) %>% summary()
kable(suptab2) %>%
  kable_classic(html_font = "Arial", full_width = FALSE)
```

Web Table 2 - Dose Response Deciles

```
# create deciles quantiles for each Austin approach
x1_quants <- map_dbl(seq(0.1, 0.9, 0.1), ~ quantile(df$x1, .x))

x2_quants <- map_dbl(seq(0.1, 0.9, 0.1), ~ quantile(df$x2, .x))
```

	x1	x2	x3	x4	x5	x6
	Min. :76.00	Min. : 96.0	Min. :69.00	Min. : 9.00	Min. :11.0	Min. : 8.00
	1st Qu.:83.00	1st Qu.:105.0	1st Qu.:75.00	1st Qu.:10.00	1st Qu.:13.0	1st Qu.:10.00
	Median :85.00	Median :107.0	Median :76.00	Median :11.00	Median :14.0	Median :10.00
	Mean :85.16	Mean :106.8	Mean :76.54	Mean :10.82	Mean :13.8	Mean :10.04
	3rd Qu.:87.00	3rd Qu.:109.0	3rd Qu.:78.00	3rd Qu.:11.00	3rd Qu.:14.0	3rd Qu.:10.00
	Max. :94.00	Max. :117.0	Max. :85.00	Max. :13.00	Max. :17.0	Max. :12.00

Decile	X1	X2	X3	X4	X5	X6
1	15.1	21.4	0.0	15	21	0
2	15.7	22.3	0.5	16	22	0
3	16.2	22.9	0.9	16	23	1
4	16.6	23.4	1.4	17	23	1
5	17.0	23.9	1.8	17	24	2
6	17.3	24.3	2.3	17	24	2
7	17.7	24.7	2.8	18	25	3
8	18.2	25.3	3.4	18	25	3
9	18.8	25.9	4.3	19	26	4

```
x3_quants <- map_dbl(seq(0.1, 0.9, 0.1), ~ quantile(df$x3, .x))

x4_quants <- map_dbl(seq(0.1, 0.9, 0.1), ~ quantile(df$x4, .x))

x5_quants <- map_dbl(seq(0.1, 0.9, 0.1), ~ quantile(df$x5, .x))

x6_quants <- map_dbl(seq(0.1, 0.9, 0.1), ~ quantile(df$x6, .x))

# print table of decile values
dec_tab <- tibble(Decile = c(1:9),
                  X1 = x1_quants,
                  X2 = x2_quants,
                  X3 = x3_quants,
                  X4 = x4_quants,
                  X5 = x5_quants,
                  X6 = x6_quants)
kable(dec_tab) %>%
  kable_classic(html_font = "Arial", full_width = FALSE)
```

Recreating Distributions from Naimi et al.

Web Table 3 - Simulation Descriptive Statistics

```
# recreate table 1
tab1 <- tibble(`Variable (Distribution)` = c("Maternal Age (normal)",
                                              "Maternal Age (skewed)",
                                              "Paternal Age (normal)",
                                              "Parity (Poisson)",
                                              "2",
                                              "3",
```

```
                                    "4",
                                    "5+",
                                    "X1 (normal, naimi) - rounded to 0.1",
                                    "X2 (normal, skewed) - rounded to 0.1",
                                    "X3 (Poisson, naimi) - rounded to 0.1",
                                    "X4 (normal, naimi) - rounded to 1",
                                    "X5 (normal, skewed) - rounded to 1",
                                    "X6 (Poisson, naimi) - rounded to 1",
                                    "Y1 (Bernoulli, naimi)",
                                    "Y2 (Bernoulli, skewed)",
                                    "Y3 (Bernoulli, naimi)",
                                    "Y4 (Bernoulli, naimi)",
                                    "Y5 (Bernoulli, skewed)",
                                    "Y6 (Bernoulli, naimi)",
                                    "Naimi Homoscedastic X",
                                    "Naimi Heteroscedastic X",
                                    "Naimi Homoscedastic Y",
                                    "Naimi Heteroscedastic Y"),
               Mean = c(mean(df$mage),
                        mean(df$mage_g),
                        mean(df$page),
                        NA,
                        mean(df$parity2),
                        mean(df$parity3),
                        mean(df$parity4),
                        mean(df$parity5),
                        mean(df$x1),
                        mean(df$x2),
                        mean(df$x3, na.rm = TRUE),
                        mean(df$x4, na.rm = TRUE),
                        mean(df$x5, na.rm = TRUE),
                        mean(df$x6, na.rm = TRUE),
                        mean(df$y1),
                        mean(df$y2),
                        mean(df$y3, na.rm = TRUE),
                        mean(df$y4, na.rm = TRUE),
                        mean(df$y5, na.rm = TRUE),
                        mean(df$y6, na.rm = TRUE),
                        mean(df$n_x1),
                        mean(df$n_x2, na.rm = TRUE),
                        mean(df$n_y1),
                        mean(df$n_y2, na.rm = TRUE)),
               Variance = c(var(df$mage),
                        var(df$mage_g),
                        var(df$page),
                        NA,
                        var(df$parity2),
                        var(df$parity3),
                        var(df$parity4),
                        var(df$parity5),
                        var(df$x1),
                        var(df$x2),
                        var(df$x3, na.rm = TRUE),
```

Variable (Distribution)	Mean	Variance
Maternal Age (normal)	29.84	21.61
Maternal Age (skewed)	30.07	15.46
Paternal Age (normal)	32.52	30.43
Parity (Poisson)		
2	0.24	0.18
3	0.07	0.07
4	0.02	0.02
5+	0.02	0.02
X1 (normal, naimi) - rounded to 0.1	16.96	2.16
X2 (normal, skewed) - rounded to 0.1	23.74	3.38
X3 (Poisson, naimi) - rounded to 0.1	2.04	2.67
X4 (normal, naimi) - rounded to 1	16.96	2.24
X5 (normal, skewed) - rounded to 1	23.74	3.45
X6 (Poisson, naimi) - rounded to 1	2.04	2.77
Y1 (Bernoulli, naimi)	0.08	0.07
Y2 (Bernoulli, skewed)	0.08	0.07
Y3 (Bernoulli, naimi)	0.09	0.08
Y4 (Bernoulli, naimi)	0.08	0.07
Y5 (Bernoulli, skewed)	0.08	0.07
Y6 (Bernoulli, naimi)	0.09	0.08
Naimi Homoscedastic X	16.96	2.16
Naimi Heteroscedastic X	2.04	2.67
Naimi Homoscedastic Y	0.08	0.07
Naimi Heteroscedastic Y	0.09	0.08

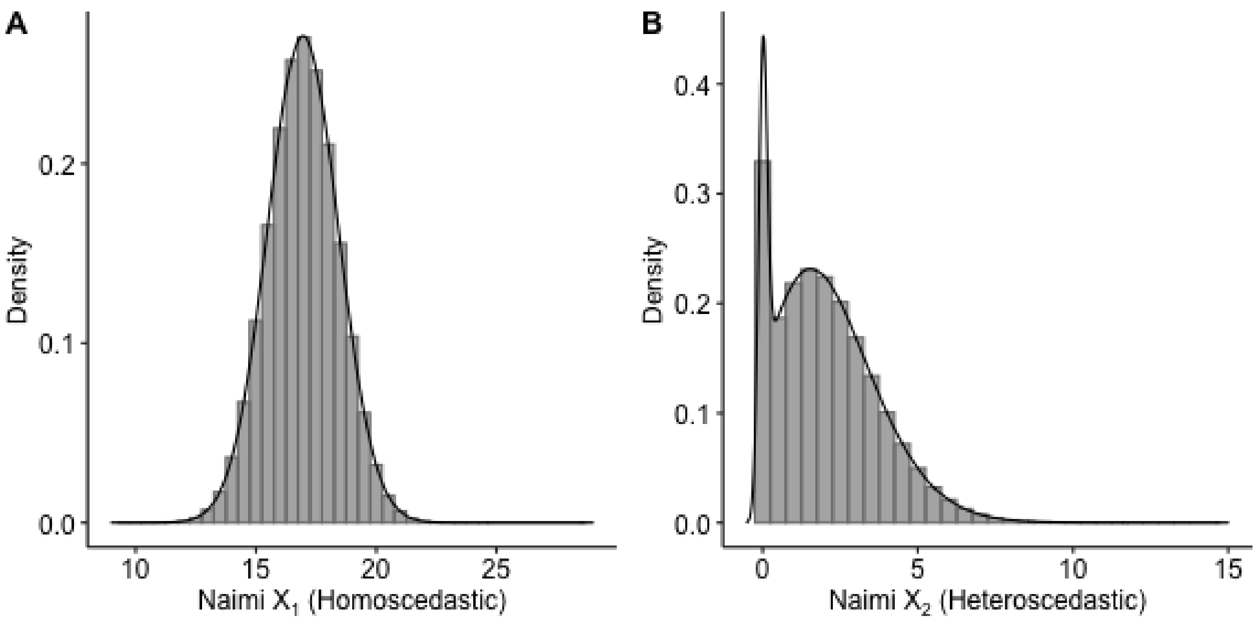
```
                        var(df$x4, na.rm = TRUE),
                        var(df$x5, na.rm = TRUE),
                        var(df$x6, na.rm = TRUE),
                        var(df$y1),
                        var(df$y2),
                        var(df$y3, na.rm = TRUE),
                        var(df$y4, na.rm = TRUE),
                        var(df$y5, na.rm = TRUE),
                        var(df$y6, na.rm = TRUE),
                        var(df$n_x1),
                        var(df$n_x2, na.rm = TRUE),
                        var(df$n_y1),
                        var(df$n_y2, na.rm = TRUE)))

# table 1
kable(tab1, digits = 2) %>%
  kable_classic(html_font = "Arial", full_width = FALSE) %>%
  add_indent(c(5:8))
```

Web Figure 1 - Continuous Exposure

```
# now create plot
naimix1 <- ggplot(df, aes(x = n_x1)) +
  geom_histogram(aes(y = ..density..), binwidth = 0.5, alpha = 0.5, color = "grey50") +
```

```r
  geom_density(adjust = 2) +
  ylab("Density") +
  scale_x_continuous(name = expression(paste("Naimi ", X[1], " (Homoscedastic)")),
                     limits = c(9, 29), breaks = c(10, 15, 20, 25)) +
  theme

naimix2 <- ggplot(df, aes(x = n_x2)) +
  geom_histogram(aes(y = ..density..), binwidth = 0.5, alpha = 0.5, color = "grey50") +
  geom_density(adjust = 2) +
  ylab("Density") +
  scale_x_continuous(name = expression(paste("Naimi ", X[2], " (Heteroscedastic)")),
                     limits = c(-0.5, 15), breaks = c(0, 5, 10, 15)) +
  theme

# recreate figure 1
ggarrange(naimix1, naimix2,
          labels = c("A", "B"))
```

```r
#ggsave("./sim_png/supfig1.1.png")
```

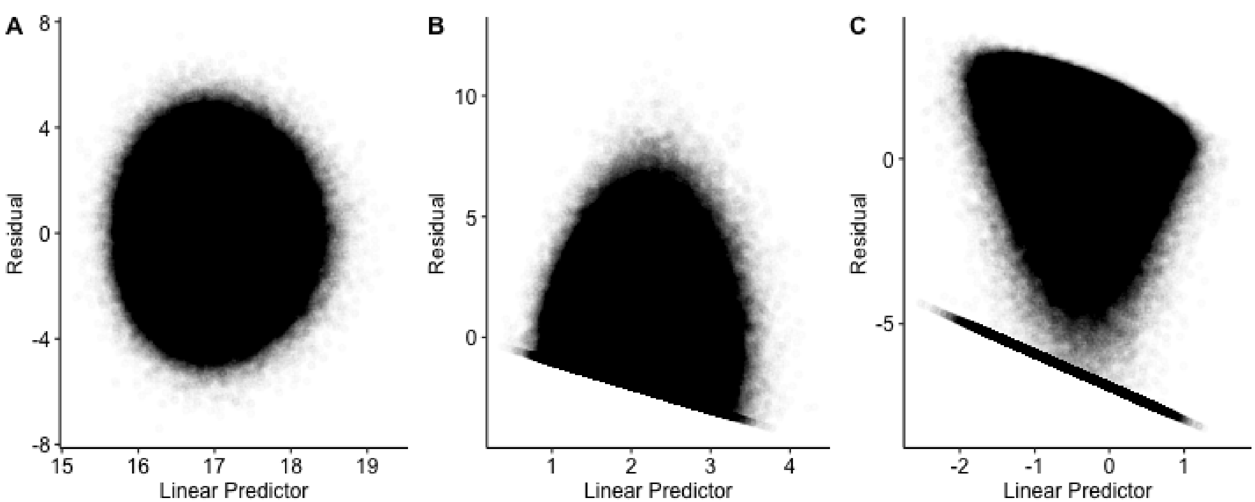


Panel A) Homoscedastic Continuous Exposure, Panel B) Heteroscedastic Continuous Exposure

Web Figure 2 - Continuous Exposure

```r
# will run ols regression on df
ols_x1_n <- ols(n_x1 ~ + mage + page + mage*page + parity2 + parity3 + parity4 +
                  parity5, data = df)
ols_x2_n <- ols(n_x2 ~ + mage + page + mage*page + parity2 + parity3 + parity4 +
                  parity5, data = df) # added 0.001 to avoid -Inf when logging
ols_x2_n_log <- ols(log(n_x2 + 0.001) ~ + mage + page + mage*page + parity2 + parity3 + parity4 +
                      parity5, data = df) # added 0.001 to avoid -Inf when logging
```

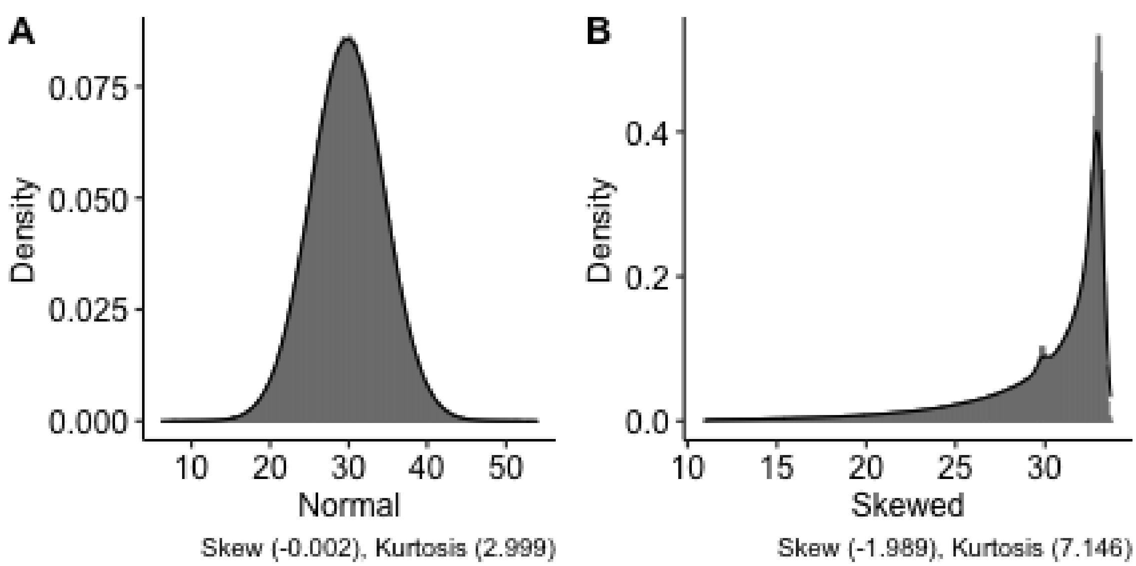
```
# linear predictors
preds_x1_n <- predict(ols_x1_n)
preds_x2_n <- predict(ols_x2_n)
preds_x2_n_log <- predict(ols_x2_n_log)

# residuals
res_x1_n <- residuals(ols_x1_n)
res_x2_n <- residuals(ols_x2_n)
res_x2_n_log <- residuals(ols_x2_n_log)

# now plot
x1_plot_n <- ggplot() +
  geom_point(aes(x = preds_x1_n, y = res_x1_n), alpha = 0.01) +
  ylab("Residual") +
  xlab("Linear Predictor") +
  theme

x2_plot_n <- ggplot() +
  geom_point(aes(x = preds_x2_n, y = res_x2_n), alpha = 0.01) +
  ylab("Residual") +
  xlab("Linear Predictor") +
  theme

x2_plot_n_log <- ggplot() +
  geom_point(aes(x = preds_x2_n_log, y = res_x2_n_log), alpha = 0.01) +
  ylab("Residual") +
  xlab("Linear Predictor") +
  theme

# combine
ggarrange(x1_plot_n, x2_plot_n, x2_plot_n_log,
          nrow = 1,
          labels = c("A", "B", "C"))
#ggsave("./sim_png/supfig1.2.png")
```



Updated Distributions

Web Figure 3 - Maternal Age Distributions

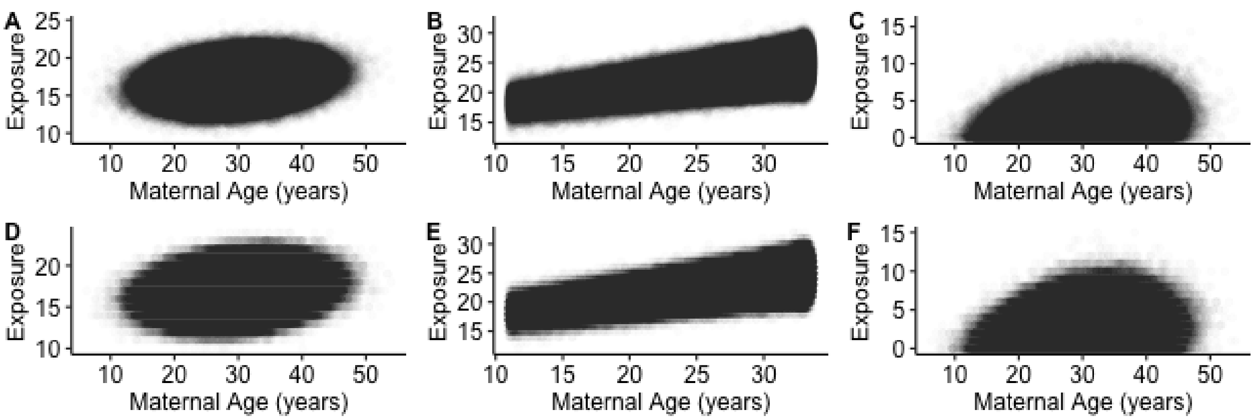
```
mage_hist <- df %>%
  ggplot(aes(x = mage)) +
  geom_histogram(aes(y = ..density..), binwidth = 0.1, alpha = 0.5, color = "grey50") +
  geom_density(adjust = 2) +
  ylab("Density") +
  xlab("Normal") +
  labs(caption = paste0("Skew (", round(moments::skewness(df$mage), 3), "), Kurtosis (",
                        round(moments::kurtosis(df$mage), 3), ")")) +
  theme

mage_g_hist <- df %>%
  ggplot(aes(x = mage_g)) +
  geom_histogram(aes(y = ..density..), binwidth = 0.1, alpha = 0.5, color = "grey50") +
  geom_density(adjust = 2) +
  ylab("Density") +
  xlab("Skewed") +
  labs(caption = paste0("Skew (", round(moments::skewness(df$mage_g), 3), "), Kurtosis (",
                        round(moments::kurtosis(df$mage_g), 3), ")")) +
  theme

ggarrange(mage_hist, mage_g_hist,
          labels = c("A", "B"))
#ggsave("./sim_png/supfig1.3.png")
```



Supplemental Figure 3 shows the updated marginal distributions of maternal age (`mage`) and skewed maternal age (`mage_g`). Despite similar means and variances in `mage` and `mage_g`, `mage` is normally distributed whereas `mage_g` is significantly left-skewed.

Web Figure 4 - Exposure-Covariate Correlations

```
supfig2_4_func <- function(exp, mage) {
  exp <- enquo(exp)
  mage <- enquo(mage)
  df %>%
    select(!!mage, !!exp) %>%
    ggplot(aes(x = !!mage, y = !!exp)) +
    geom_point(alpha = 0.01) +
    ylab("Exposure") +
    xlab("Maternal Age (years)") +
    theme
}
# combine
ggarrange(supfig2_4_func(x1, mage),
          supfig2_4_func(x2, mage_g),
          supfig2_4_func(x3, mage),
          supfig2_4_func(x4, mage),
          supfig2_4_func(x5, mage_g),
          supfig2_4_func(x6, mage),
          labels = c("A", "B", "C", "D", "E", "F"),
          nrow = 2, ncol = 3,
          font.label = list(size = 12))
# save plot
#ggsave("./sim_png/supfig1.4.png")
```



Marginal and Conditional Exposure Distributions

Figure 1 - Marginal and Conditional Exposure Distribution

```
# Marginal Exposure Distribution

# now create plot
dens_x1 <- ggplot(df, aes(x = x1)) +
  geom_histogram(aes(y = ..density..), binwidth = 0.1, alpha = 0.5, color = "grey50") +
  geom_density(adjust = 2) +
  ylab("Density") +
```

```r
  scale_x_continuous(name = expression(paste(X[1]))) +
  # labs(caption = paste0("Skew (", round(moments::skewness(df$x1), 3),
  #        "), Kurtosis (", round(moments::kurtosis(df$x1), 3), ")")) +
  theme +
  theme(text = element_text(size = 8.5))

dens_x2 <- ggplot(df, aes(x = x2)) +
  geom_histogram(aes(y = ..density..), binwidth = 0.1, alpha = 0.5, color = "grey50") +
  geom_density(adjust = 2) +
  ylab("Density") +
  scale_x_continuous(name = expression(paste(X[2])), limits = c(10, 35),
                     breaks = c(10, 15, 20, 25, 30, 35)) +
  # labs(caption = paste0("Skew (", round(moments::skewness(df$x2), 3),
  #        "), Kurtosis (", round(moments::kurtosis(df$x2), 3), ")")) +
  theme +
  theme(text = element_text(size = 8.5))

dens_x3 <- ggplot(df, aes(x = x3)) +
  geom_histogram(aes(y = ..density..), binwidth = 0.1, alpha = 0.5, color = "grey50") +
  geom_density(adjust = 2) +
  ylab("Density") +
  scale_x_continuous(name = expression(paste(X[3])), limits = c(-0.1, 20),
                     breaks = c(0, 5, 10 ,20)) +
  # labs(caption = "  ") +
  theme +
  theme(text = element_text(size = 8.5))

dens_x4 <- ggplot(df, aes(x = x4)) +
  geom_histogram(aes(y = ..density..), binwidth = 1, alpha = 0.5, color = "grey50") +
  #geom_density(adjust = 2) +
  ylab("Density") +
  scale_x_continuous(name = expression(paste(X[4]))) +
  # labs(caption = paste0("Skew (", round(moments::skewness(df$x4), 3),
  #        "), Kurtosis (", round(moments::kurtosis(df$x4), 3), ")")) +
  theme +
  theme(text = element_text(size = 8.5))

dens_x5 <- ggplot(df, aes(x = x5)) +
  geom_histogram(aes(y = ..density..), binwidth = 1, alpha = 0.5, color = "grey50") +
  #geom_density(adjust = 2) +
  ylab("Density") +
  scale_x_continuous(name = expression(paste(X[5])), limits = c(10, 35),
                     breaks = c(10, 15, 20, 25, 30, 35)) +
  # labs(caption = paste0("Skew (", round(moments::skewness(df$x5), 3),
  #        "), Kurtosis (", round(moments::kurtosis(df$x5), 3), ")")) +
  theme +
  theme(text = element_text(size = 8.5))

dens_x6 <- ggplot(df, aes(x = x6)) +
  geom_histogram(aes(y = ..density..), binwidth = 1, alpha = 0.5, color = "grey50") +
  #geom_density(adjust = 2) +
  ylab("Density") +
  scale_x_continuous(name = expression(paste(X[6])), limits = c(-1, 20),
```

```
                      breaks = c(0, 5, 10 ,20)) +
  # labs(caption = "  ") +
  theme +
  theme(text = element_text(size = 8.5))

# Conditional Exposure Distribution

# will run ols regression on df
ols_x1 <- ols(x1 ~ + mage + page + mage*page + parity2 + parity3 + parity4 +
                parity5, data = df)
ols_x2 <- ols(x2 ~ + mage_g + page + mage_g*page + parity2 + parity3 + parity4 +
                parity5, data = df)
ols_x3 <- ols(x3 ~ + mage + page + mage*page + parity2 + parity3 + parity4 +
                parity5, data = df)
ols_x4 <- ols(x4 ~ + mage + page + mage*page + parity2 + parity3 + parity4 +
                parity5, data = df)
ols_x5 <- ols(x5 ~ + mage_g + page + mage_g*page + parity2 + parity3 + parity4 +
                parity5, data = df)
ols_x6 <- ols(x6 ~ + mage + page + mage*page + parity2 + parity3 + parity4 +
                parity5, data = df)

# linear predictors
preds_x1 <- predict(ols_x1)
preds_x2 <- predict(ols_x2)
preds_x3 <- predict(ols_x3)
preds_x4 <- predict(ols_x4)
preds_x5 <- predict(ols_x5)
preds_x6 <- predict(ols_x6)

# residuals
res_x1 <- residuals(ols_x1)
res_x2 <- residuals(ols_x2)
res_x3 <- residuals(ols_x3)
res_x4 <- residuals(ols_x4)
res_x5 <- residuals(ols_x5)
res_x6 <- residuals(ols_x6)

# now plot
x1_plot <- ggplot() +
  geom_point(aes(x = preds_x1, y = res_x1), alpha = 0.01) +
  ylab("Residual") +
  scale_x_continuous(name = expression(paste("Linear Predictor (", X[1], ")"))) +
  theme +
  theme(text = element_text(size = 8.5))

x2_plot <- ggplot() +
  geom_point(aes(x = preds_x2, y = res_x2), alpha = 0.01) +
  ylab("Residual") +
  scale_x_continuous(name = expression(paste("Linear Predictor (", X[2], ")"))) +
  theme +
  theme(text = element_text(size = 8.5))

x3_plot <- ggplot() +
```

```r
  geom_point(aes(x = preds_x3, y = res_x3), alpha = 0.01) +
  ylab("Residual") +
  scale_x_continuous(name = expression(paste("Linear Predictor (", X[3], ")"))) +
  theme +
  theme(text = element_text(size = 8.5))

x4_plot <- ggplot() +
  geom_point(aes(x = preds_x4, y = res_x4), alpha = 0.01) +
  ylab("Residual") +
  scale_x_continuous(name = expression(paste("Linear Predictor (", X[4], ")"))) +
  theme +
  theme(text = element_text(size = 8))

x5_plot <- ggplot() +
  geom_point(aes(x = preds_x5, y = res_x5), alpha = 0.01) +
  ylab("Residual") +
  scale_x_continuous(name = expression(paste("Linear Predictor (", X[5], ")"))) +
  theme +
  theme(text = element_text(size = 8.5))

x6_plot <- ggplot() +
  geom_point(aes(x = preds_x6, y = res_x6), alpha = 0.01) +
  ylab("Residual") +
  scale_x_continuous(name = expression(paste("Linear Predictor (", X[6], ")"))) +
  theme +
  theme(text = element_text(size = 8.5))

# combine
ggarrange(dens_x1, x1_plot,
          dens_x2, x2_plot,
          dens_x3, x3_plot,
          dens_x4, x4_plot,
          dens_x5, x5_plot,
          dens_x6, x6_plot,
          labels = c("A)", "B)", "C)", "D)", "E)", "F)",
                     "G)", "H)", "I)", "J)", "K)", "L)"),
          nrow = 6, ncol = 2,
          font.label = list(size = 8.5, face = "plain"))
# save plot
ggsave("fin_figs/fig1.tiff", width = 7, height = 7)
```

Figure 1 Panels

```r
# Panel A
dens_x1
ggsave("fin_figs/fig1a.pdf", width = 3.5, height = 1.167)
embed_fonts("fin_figs/fig1a.pdf")

# Panel B
x1_plot
ggsave("fin_figs/fig1b.tiff", width = 3.5, height = 1.167)
```

```
# Panel C
dens_x2
ggsave("fin_figs/fig1c.pdf", width = 3.5, height = 1.167)
embed_fonts("fin_figs/fig1c.pdf")

# Panel D
x2_plot
ggsave("fin_figs/fig1d.tiff", width = 3.5, height = 1.167)

# Panel E
dens_x3
ggsave("fin_figs/fig1e.pdf", width = 3.5, height = 1.167)
embed_fonts("fin_figs/fig1e.pdf")

# Panel F
x3_plot
ggsave("fin_figs/fig1f.tiff", width = 3.5, height = 1.167)

# Panel G
dens_x4
ggsave("fin_figs/fig1g.pdf", width = 3.5, height = 1.167)
embed_fonts("fin_figs/fig1g.pdf")

# Panel H
x4_plot
ggsave("fin_figs/fig1h.tiff", width = 3.5, height = 1.167)

# Panel I
dens_x5
ggsave("fin_figs/fig1i.pdf", width = 3.5, height = 1.167)
embed_fonts("fin_figs/fig1i.pdf")

# Panel J
x5_plot
ggsave("fin_figs/fig1j.tiff", width = 3.5, height = 1.167)

# Panel K
dens_x6
ggsave("fin_figs/fig1k.pdf", width = 3.5, height = 1.167)
embed_fonts("fin_figs/fig1k.pdf")

# Panel L
x6_plot
ggsave("fin_figs/fig1l.tiff", width = 3.5, height = 1.167)
```

Stabilized Inverse Probability Weight Assessments

```
# make dataframe that gives the mean IPW weights for each simulation
# (will then take mean, min, and max of those)
mean_wts <- df %>%
  select(i, x1_ols_wts:x6_olr_wts) %>%
```

```r
  group_by(i) %>%
  summarise(x1_ols_wts = mean(x1_ols_wts),
            x1_cbgps_wts = mean(x1_cbgps_wts),
            x1_npcbgps_wts = mean(x1_npcbgps_wts),
            x1_qb10_wts = mean(x1_qb10_wts),
            x1_qb15_wts = mean(x1_qb15_wts),
            x1_qb20_wts = mean(x1_qb20_wts),
            x1_olr_wts = mean(x1_olr_wts),
            x2_ols_wts = mean(x2_ols_wts),
            x2_cbgps_wts = mean(x2_cbgps_wts),
            x2_npcbgps_wts = mean(x2_npcbgps_wts),
            x2_qb10_wts = mean(x2_qb10_wts),
            x2_qb15_wts = mean(x2_qb15_wts),
            x2_qb20_wts = mean(x2_qb20_wts),
            x2_olr_wts = mean(x2_olr_wts),
            x3_ols_wts = mean(x3_ols_wts),
            x3_cbgps_wts = mean(x3_cbgps_wts),
            x3_npcbgps_wts = mean(x3_npcbgps_wts),
            x3_qb10_wts = mean(x3_qb10_wts),
            x3_qb15_wts = mean(x3_qb15_wts),
            x3_qb20_wts = mean(x3_qb20_wts),
            x3_olr_wts = mean(x3_olr_wts),
            x4_ols_wts = mean(x4_ols_wts),
            x4_cbgps_wts = mean(x4_cbgps_wts),
            x4_npcbgps_wts = mean(x4_npcbgps_wts),
            x4_olr_wts = mean(x4_olr_wts),
            x5_ols_wts = mean(x5_ols_wts),
            x5_cbgps_wts = mean(x5_cbgps_wts),
            x5_npcbgps_wts = mean(x5_npcbgps_wts),
            x5_olr_wts = mean(x5_olr_wts),
            x6_ols_wts = mean(x6_ols_wts),
            x6_cbgps_wts = mean(x6_cbgps_wts),
            x6_npcbgps_wts = mean(x6_npcbgps_wts),
            x6_olr_wts = mean(x6_olr_wts))

# have to get mean (min, max) of weights from different exposure scenarios
tab2 <- tibble(Method = c("Ordinary least squares",
                          "Covariate balancing generalized propensity score",
                          "Non-parametric covariate balancing generalized propensity score",
                          "Quantile binning categories",
                          "10",
                          "15",
                          "20",
                          "Ordinal logistic regression"),
               `Mean (min, max)` = c(paste0(round(mean(mean_wts$x1_ols_wts), 2), " (",
                                            round(min(mean_wts$x1_ols_wts), 2), ", ",
                                            round(max(mean_wts$x1_ols_wts), 2), ")"),
                                     paste0(round(mean(mean_wts$x1_cbgps_wts), 2), " (",
                                            round(min(mean_wts$x1_cbgps_wts), 2), ", ",
                                            round(max(mean_wts$x1_cbgps_wts), 2), ")"),
                                     paste0(round(mean(mean_wts$x1_npcbgps_wts), 2), " (",
                                            round(min(mean_wts$x1_npcbgps_wts), 2), ", ",
                                            round(max(mean_wts$x1_npcbgps_wts), 2), ")"),
```

```
                              NA,
                              paste0(round(mean(mean_wts$x1_qb10_wts), 2), " (",
                                     round(min(mean_wts$x1_qb10_wts), 2), ", ",
                                     round(max(mean_wts$x1_qb10_wts), 2), ")"),
                              paste0(round(mean(mean_wts$x1_qb15_wts), 2), " (",
                                     round(min(mean_wts$x1_qb15_wts), 2), ", ",
                                     round(max(mean_wts$x1_qb15_wts), 2), ")"),
                              paste0(round(mean(mean_wts$x1_qb20_wts), 2), " (",
                                     round(min(mean_wts$x1_qb20_wts), 2), ", ",
                                     round(max(mean_wts$x1_qb20_wts), 2), ")"),
                              paste0(round(mean(mean_wts$x1_olr_wts), 2), " (",
                                     round(min(mean_wts$x1_olr_wts), 2), ", ",
                                     round(max(mean_wts$x1_olr_wts), 2), ")")),
          `Mean (min, max) ` = c(paste0(round(mean(mean_wts$x2_ols_wts), 2), " (",
                                     round(min(mean_wts$x2_ols_wts), 2), ", ",
                                     round(max(mean_wts$x2_ols_wts), 2), ")"),
                              paste0(round(mean(mean_wts$x2_cbgps_wts), 2), " (",
                                     round(min(mean_wts$x2_cbgps_wts), 2), ", ",
                                     round(max(mean_wts$x2_cbgps_wts), 2), ")"),
                              paste0(round(mean(mean_wts$x2_npcbgps_wts), 2), " (",
                                     round(min(mean_wts$x2_npcbgps_wts), 2), ", ",
                                     round(max(mean_wts$x2_npcbgps_wts), 2), ")"),
                              NA,
                              paste0(round(mean(mean_wts$x2_qb10_wts), 2), " (",
                                     round(min(mean_wts$x2_qb10_wts), 2), ", ",
                                     round(max(mean_wts$x2_qb10_wts), 2), ")"),
                              paste0(round(mean(mean_wts$x2_qb15_wts), 2), " (",
                                     round(min(mean_wts$x2_qb15_wts), 2), ", ",
                                     round(max(mean_wts$x2_qb15_wts), 2), ")"),
                              paste0(round(mean(mean_wts$x2_qb20_wts), 2), " (",
                                     round(min(mean_wts$x2_qb20_wts), 2), ", ",
                                     round(max(mean_wts$x2_qb20_wts), 2), ")"),
                              paste0(round(mean(mean_wts$x2_olr_wts), 2), " (",
                                     round(min(mean_wts$x2_olr_wts), 2), ", ",
                                     round(max(mean_wts$x2_olr_wts), 2), ")")),
          `Mean (min, max)  ` = c(paste0(round(mean(mean_wts$x3_ols_wts), 2), " (",
                                     round(min(mean_wts$x3_ols_wts), 2), ", ",
                                     round(max(mean_wts$x3_ols_wts), 2), ")"),
                              paste0(round(mean(mean_wts$x3_cbgps_wts), 2), " (",
                                     round(min(mean_wts$x3_cbgps_wts), 2), ", ",
                                     round(max(mean_wts$x3_cbgps_wts), 2), ")"),
                              paste0(round(mean(mean_wts$x3_npcbgps_wts), 2), " (",
                                     round(min(mean_wts$x3_npcbgps_wts), 2), ", ",
                                     round(max(mean_wts$x3_npcbgps_wts), 2), ")"),
                              NA,
                              paste0(round(mean(mean_wts$x3_qb10_wts), 2), " (",
                                     round(min(mean_wts$x3_qb10_wts), 2), ", ",
                                     round(max(mean_wts$x3_qb10_wts), 2), ")"),
                              paste0(round(mean(mean_wts$x3_qb15_wts), 2), " (",
                                     round(min(mean_wts$x3_qb15_wts), 2), ", ",
                                     round(max(mean_wts$x3_qb15_wts), 2), ")"),
                              paste0(round(mean(mean_wts$x3_qb20_wts), 2), " (",
                                     round(min(mean_wts$x3_qb20_wts), 2), ", ",
```

```
                            round(max(mean_wts$x3_qb20_wts), 2), ")"),
                     paste0(round(mean(mean_wts$x3_olr_wts), 2), " (",
                            round(min(mean_wts$x3_olr_wts), 2), ", ",
                            round(max(mean_wts$x3_olr_wts), 2), ")")),
`Mean (min, max)   ` = c(paste0(round(mean(df$x4_ols_wts), 2), " (",
                            round(min(df$x4_ols_wts), 2), ", ",
                            round(max(df$x4_ols_wts), 2), ")"),
                     paste0(round(mean(df$x4_cbgps_wts), 2), " (",
                            round(min(df$x4_cbgps_wts), 2), ", ",
                            round(max(df$x4_cbgps_wts), 2), ")"),
                     paste0(round(mean(mean_wts$x4_npcbgps_wts), 2), " (",
                            round(min(mean_wts$x4_npcbgps_wts), 2), ", ",
                            round(max(mean_wts$x4_npcbgps_wts), 2), ")"),
                     NA,
                     NA,
                     NA,
                     NA,
                     paste0(round(mean(df$x4_olr_wts), 2), " (",
                            round(min(df$x4_olr_wts), 2), ", ",
                            round(max(df$x4_olr_wts), 2), ")")),
`Mean (min, max)    ` = c(paste0(round(mean(df$x5_ols_wts), 2), " (",
                            round(min(df$x5_ols_wts), 2), ", ",
                            round(max(df$x5_ols_wts), 2), ")"),
                     paste0(round(mean(df$x5_cbgps_wts), 2), " (",
                            round(min(df$x5_cbgps_wts), 2), ", ",
                            round(max(df$x5_cbgps_wts), 2), ")"),
                     paste0(round(mean(mean_wts$x5_npcbgps_wts), 2), " (",
                            round(min(mean_wts$x5_npcbgps_wts), 2), ", ",
                            round(max(mean_wts$x5_npcbgps_wts), 2), ")"),
                     NA,
                     NA,
                     NA,
                     NA,
                     paste0(round(mean(df$x5_olr_wts), 2), " (",
                            round(min(df$x5_olr_wts), 2), ", ",
                            round(max(df$x5_olr_wts), 2), ")")),
`Mean (min, max)     ` = c(paste0(round(mean(df$x6_ols_wts), 2), " (",
                            round(min(df$x6_ols_wts), 2), ", ",
                            round(max(df$x6_ols_wts), 2), ")"),
                     paste0(round(mean(df$x6_cbgps_wts), 2), " (",
                            round(min(df$x6_cbgps_wts), 2), ", ",
                            round(max(df$x6_cbgps_wts), 2), ")"),
                     paste0(round(mean(mean_wts$x6_npcbgps_wts), 2), " (",
                            round(min(mean_wts$x6_npcbgps_wts), 2), ", ",
                            round(max(mean_wts$x6_npcbgps_wts), 2), ")"),
                     NA,
                     NA,
                     NA,
                     NA,
                     paste0(round(mean(df$x6_olr_wts), 2), " (",
                            round(min(df$x6_olr_wts), 2), ", ",
                            round(max(df$x6_olr_wts), 2), ")"))
)
```

Covariate Balance

```
# will need to calculate number of covariates with correlation greated than 0.1 in all exposure scenari
# start with a function (ignore QB for now)

covbal_func <- function(data){
  # simulation number
  i <- data$i[1]

  # start with formulas for different exposures
  x1_formula <- formula(x1 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)
  x2_formula <- formula(x2 ~ mage_g + page + mage_g*page + parity2 + parity3 + parity4 + parity5)
  x3_formula <- formula(x3 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)
  x4_formula <- formula(x4 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)
  x5_formula <- formula(x6 ~ mage_g + page + mage_g*page + parity2 + parity3 + parity4 + parity5)
  x6_formula <- formula(x6 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)

  # now calculate balance
  bal_tab_x1 <- bal.tab(x1_formula, data = data,
        weights = list(OLS = "x1_ols_wts",
                       CBGPS = "x1_cbgps_wts",
                       NPCGPS = "x1_npcbgps_wts",
                       CPM = "x1_olr_wts"),
        stats = c("c"),
        un = TRUE, thresholds = c(cor = .1))
  bal_tab_x2 <- bal.tab(x2_formula, data = data,
        weights = list(OLS = "x2_ols_wts",
                       CBGPS = "x2_cbgps_wts",
                       NPCGPS = "x2_npcbgps_wts",
                       CPM = "x2_olr_wts"),
        stats = c("c"),
        un = TRUE, thresholds = c(cor = .1))
  bal_tab_x3 <- bal.tab(x3_formula, data = data,
        weights = list(OLS = "x3_ols_wts",
                       CBGPS = "x3_cbgps_wts",
                       NPCGPS = "x3_npcbgps_wts",
                       CPM = "x3_olr_wts"),
        stats = c("c"),
        un = TRUE, thresholds = c(cor = .1))
  bal_tab_x4 <- bal.tab(x4_formula, data = data,
        weights = list(OLS = "x4_ols_wts",
                       CBGPS = "x4_cbgps_wts",
                       NPCGPS = "x4_npcbgps_wts",
                       CPM = "x4_olr_wts"),
        stats = c("c"),
        un = TRUE, thresholds = c(cor = .1))
  bal_tab_x5 <- bal.tab(x5_formula, data = data,
        weights = list(OLS = "x5_ols_wts",
                       CBGPS = "x5_cbgps_wts",
                       NPCGPS = "x5_npcbgps_wts",
                       CPM = "x5_olr_wts"),
        stats = c("c"),
        un = TRUE, thresholds = c(cor = .1))
```

```
bal_tab_x6 <- bal.tab(x6_formula, data = data,
      weights = list(OLS = "x6_ols_wts",
                     CBGPS = "x6_cbgps_wts",
                     NPCGPS = "x6_npcbgps_wts",
                     CPM = "x6_olr_wts"),
      stats = c("c"),
      un = TRUE, thresholds = c(cor = .1))

# now calculate quantile binning correlations

# qb10
x1_qb10form <- formula(x1_qb10 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)
x2_qb10form <- formula(x2_qb10 ~ mage_g + page + mage_g*page + parity2 + parity3 + parity4 + parity5)
x3_qb10form <- formula(x3_qb10 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)

bal_tab_x1_qb10 <- bal.tab(x1_qb10form, data = data, weights = "x1_qb10_wts", stats = c("c"),
                           un = TRUE, thresholds = c(cor = .1))
bal_tab_x2_qb10 <- bal.tab(x2_qb10form, data = data, weights = "x2_qb10_wts", stats = c("c"),
                           un = TRUE, thresholds = c(cor = .1))
bal_tab_x3_qb10 <- bal.tab(x3_qb10form, data = data, weights = "x3_qb10_wts", stats = c("c"),
                           un = TRUE, thresholds = c(cor = .1))

# qb15
x1_qb15form <- formula(x1_qb15 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)
x2_qb15form <- formula(x2_qb15 ~ mage_g + page + mage_g*page + parity2 + parity3 + parity4 + parity5)
x3_qb15form <- formula(x3_qb15 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)

bal_tab_x1_qb15 <- bal.tab(x1_qb15form, data = data, weights = "x1_qb15_wts", stats = c("c"),
                           un = TRUE, thresholds = c(cor = .1))
bal_tab_x2_qb15 <- bal.tab(x2_qb15form, data = data, weights = "x2_qb15_wts", stats = c("c"),
                           un = TRUE, thresholds = c(cor = .1))
bal_tab_x3_qb15 <- bal.tab(x3_qb15form, data = data, weights = "x3_qb15_wts", stats = c("c"),
                           un = TRUE, thresholds = c(cor = .1))

# qb20
x1_qb20form <- formula(x1_qb20 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)
x2_qb20form <- formula(x2_qb20 ~ mage_g + page + mage_g*page + parity2 + parity3 + parity4 + parity5)
x3_qb20form <- formula(x3_qb20 ~ mage + page + mage*page + parity2 + parity3 + parity4 + parity5)

bal_tab_x1_qb20 <- bal.tab(x1_qb20form, data = data, weights = "x1_qb20_wts", stats = c("c"),
                           un = TRUE, thresholds = c(cor = .1))
bal_tab_x2_qb20 <- bal.tab(x2_qb20form, data = data, weights = "x2_qb20_wts", stats = c("c"),
                           un = TRUE, thresholds = c(cor = .1))
bal_tab_x3_qb20 <- bal.tab(x3_qb20form, data = data, weights = "x3_qb20_wts", stats = c("c"),
                           un = TRUE, thresholds = c(cor = .1))

# now combine into output dataframe
data_frame(i,
           x1_uw = sum(bal_tab_x1$Balance$Corr.Un < 0.1),
           x1_ols = bal_tab_x1$Balanced.correlations[2, 1],
           x1_cbgps = bal_tab_x1$Balanced.correlations[2, 2],
           x1_npcbgps = bal_tab_x1$Balanced.correlations[2, 3],
           x1_qb10 = bal_tab_x1_qb10$Balanced.correlations[2, 1],
```

```
              x1_qb15 = bal_tab_x1_qb15$Balanced.correlations[2, 1],
              x1_qb20 = bal_tab_x1_qb20$Balanced.correlations[2, 1],
              x1_olr = bal_tab_x1$Balanced.correlations[2, 4],
              x2_uw = sum(bal_tab_x2$Balance$Corr.Un < 0.1),
              x2_ols = bal_tab_x2$Balanced.correlations[2, 1],
              x2_cbgps = bal_tab_x2$Balanced.correlations[2, 2],
              x2_npcbgps = bal_tab_x2$Balanced.correlations[2, 3],
              x2_qb10 = bal_tab_x2_qb10$Balanced.correlations[2, 1],
              x2_qb15 = bal_tab_x2_qb15$Balanced.correlations[2, 1],
              x2_qb20 = bal_tab_x2_qb20$Balanced.correlations[2, 1],
              x2_olr = bal_tab_x2$Balanced.correlations[2, 4],
              x3_uw = sum(bal_tab_x3$Balance$Corr.Un < 0.1),
              x3_ols = bal_tab_x3$Balanced.correlations[2, 1],
              x3_cbgps = bal_tab_x3$Balanced.correlations[2, 2],
              x3_npcbgps = bal_tab_x3$Balanced.correlations[2, 3],
              x3_qb10 = bal_tab_x3_qb10$Balanced.correlations[2, 1],
              x3_qb15 = bal_tab_x3_qb15$Balanced.correlations[2, 1],
              x3_qb20 = bal_tab_x3_qb20$Balanced.correlations[2, 1],
              x3_olr = bal_tab_x3$Balanced.correlations[2, 4],
              x4_uw = sum(bal_tab_x4$Balance$Corr.Un < 0.1),
              x4_ols = bal_tab_x4$Balanced.correlations[2, 1],
              x4_cbgps = bal_tab_x4$Balanced.correlations[2, 2],
              x4_npcbgps = bal_tab_x4$Balanced.correlations[2, 3],
              x4_qb10 = NA,
              x4_qb15 = NA,
              x4_qb20 = NA,
              x4_olr = bal_tab_x4$Balanced.correlations[2, 4],
              x5_uw = sum(bal_tab_x5$Balance$Corr.Un < 0.1),
              x5_ols = bal_tab_x5$Balanced.correlations[2, 1],
              x5_cbgps = bal_tab_x5$Balanced.correlations[2, 2],
              x5_npcbgps = bal_tab_x5$Balanced.correlations[2, 3],
              x5_qb10 = NA,
              x5_qb15 = NA,
              x5_qb20 = NA,
              x5_olr = bal_tab_x5$Balanced.correlations[2, 4],
              x6_uw = sum(bal_tab_x6$Balance$Corr.Un < 0.1),
              x6_ols = bal_tab_x6$Balanced.correlations[2, 1],
              x6_cbgps = bal_tab_x6$Balanced.correlations[2, 2],
              x6_npcbgps = bal_tab_x6$Balanced.correlations[2, 3],
              x6_qb10 = NA,
              x6_qb15 = NA,
              x6_qb20 = NA,
              x6_olr = bal_tab_x6$Balanced.correlations[2, 4])
}

# # get covariate balance across all simulations
# covbal <- map_df(sims[1:10], ~ covbal_func(.x))

# run in parallel with furrr
plan(multisession, workers = 7)
covbal <- future_map_dfr(sims, ~ covbal_func(.x))

# save
```

```
Save(covbal)
```

```
# load covbal
Load(covbal)

# now make table of mean squared error, which is the mean of the squared biases (or errors)
covbal_tab <- tibble(Method = c("Unweighted",
                                "Ordinary least squares",
                          "Covariate balancing generalized propensity score",
                          "Non-parametric covariate balancing generalized propensity score",
                          "Quantile binning categories",
                          "10",
                          "15",
                          "20",
                          "Ordinal logistic regression"),
               `Mean (min, max)` = c(paste0(round(mean(covbal$x1_uw), 2), " (",
                                           min(covbal$x1_uw), ", ",
                                           max(covbal$x1_uw), ")"),
                                     paste0(round(mean(covbal$x1_ols), 2), " (",
                                           min(covbal$x1_ols), ", ",
                                           max(covbal$x1_ols), ")"),
                                     paste0(round(mean(covbal$x1_cbgps), 2), " (",
                                           min(covbal$x1_cbgps), ", ",
                                           max(covbal$x1_cbgps), ")"),
                                     paste0(round(mean(covbal$x1_npcbgps), 2), " (",
                                           min(covbal$x1_npcbgps), ", ",
                                           max(covbal$x1_npcbgps), ")"),
                                     NA,
                                     paste0(round(mean(covbal$x1_qb10), 2), " (",
                                           min(covbal$x1_qb10), ", ",
                                           max(covbal$x1_qb10), ")"),
                                     paste0(round(mean(covbal$x1_qb15), 2), " (",
                                           min(covbal$x1_qb15), ", ",
                                           max(covbal$x1_qb15), ")"),
                                     paste0(round(mean(covbal$x1_qb20), 2), " (",
                                           min(covbal$x1_qb20), ", ",
                                           max(covbal$x1_qb20), ")"),
                                     paste0(round(mean(covbal$x1_olr), 2), " (",
                                           min(covbal$x1_olr), ", ",
                                           max(covbal$x1_olr), ")")),
               `Mean (min, max) ` = c(paste0(round(mean(covbal$x2_uw), 2), " (",
                                           min(covbal$x2_uw), ", ",
                                           max(covbal$x2_uw), ")"),
                                     paste0(round(mean(covbal$x2_ols), 2), " (",
                                           min(covbal$x2_ols), ", ",
                                           max(covbal$x2_ols), ")"),
                                     paste0(round(mean(covbal$x2_cbgps), 2), " (",
                                           min(covbal$x2_cbgps), ", ",
                                           max(covbal$x2_cbgps), ")"),
                                     paste0(round(mean(covbal$x2_npcbgps), 2), " (",
                                           min(covbal$x2_npcbgps), ", ",
                                           max(covbal$x2_npcbgps), ")"),
                                     NA,
                                     paste0(round(mean(covbal$x2_qb10), 2), " (",
```

```r
                                        min(covbal$x2_qb10), ", ",
                                        max(covbal$x2_qb10), ")"),
                                 paste0(round(mean(covbal$x2_qb15), 2), " (",
                                        min(covbal$x2_qb15), ", ",
                                        max(covbal$x2_qb15), ")"),
                                 paste0(round(mean(covbal$x2_qb20), 2), " (",
                                        min(covbal$x2_qb20), ", ",
                                        max(covbal$x2_qb20), ")"),
                                 paste0(round(mean(covbal$x2_olr), 2), " (",
                                        min(covbal$x2_olr), ", ",
                                        max(covbal$x2_olr), ")")),
              `Mean (min, max)  ` = c(paste0(round(mean(covbal$x3_uw), 2), " (",
                                        min(covbal$x3_uw), ", ",
                                        max(covbal$x3_uw), ")"),
                                 paste0(round(mean(covbal$x3_ols), 2), " (",
                                        min(covbal$x3_ols), ", ",
                                        max(covbal$x3_ols), ")"),
                                 paste0(round(mean(covbal$x3_cbgps), 2), " (",
                                        min(covbal$x3_cbgps), ", ",
                                        max(covbal$x3_cbgps), ")"),
                                 paste0(round(mean(covbal$x3_npcbgps), 2), " (",
                                        min(covbal$x3_npcbgps), ", ",
                                        max(covbal$x3_npcbgps), ")"),
                                 NA,
                                 paste0(round(mean(covbal$x3_qb10), 2), " (",
                                        min(covbal$x3_qb10), ", ",
                                        max(covbal$x3_qb10), ")"),
                                 paste0(round(mean(covbal$x3_qb15), 2), " (",
                                        min(covbal$x3_qb15), ", ",
                                        max(covbal$x3_qb15), ")"),
                                 paste0(round(mean(covbal$x3_qb20), 2), " (",
                                        min(covbal$x3_qb20), ", ",
                                        max(covbal$x3_qb20), ")"),
                                 paste0(round(mean(covbal$x3_olr), 2), " (",
                                        min(covbal$x3_olr), ", ",
                                        max(covbal$x3_olr), ")")),
              `Mean (min, max)   ` = c(paste0(round(mean(covbal$x4_uw), 2), " (",
                                        min(covbal$x4_uw), ", ",
                                        max(covbal$x4_uw), ")"),
                                    paste0(round(mean(covbal$x4_ols), 2), " (",
                                        min(covbal$x4_ols), ", ",
                                        max(covbal$x4_ols), ")"),
                                 paste0(round(mean(covbal$x4_cbgps), 2), " (",
                                        min(covbal$x4_cbgps), ", ",
                                        max(covbal$x4_cbgps), ")"),
                                 paste0(round(mean(covbal$x4_npcbgps), 2), " (",
                                        min(covbal$x4_npcbgps), ", ",
                                        max(covbal$x4_npcbgps), ")"),
                                 NA,
                                 NA,
                                 NA,
                                 NA,
                                 paste0(round(mean(covbal$x4_olr), 2), " (",
```

```
                                    min(covbal$x4_olr), ", ",
                                    max(covbal$x4_olr), ")")),
               `Mean (min, max)    ` = c(paste0(round(mean(covbal$x5_uw), 2), " (",
                                    min(covbal$x5_uw), ", ",
                                    max(covbal$x5_uw), ")"),
                                 paste0(round(mean(covbal$x5_ols), 2), " (",
                                    min(covbal$x5_ols), ", ",
                                    max(covbal$x5_ols), ")"),
                             paste0(round(mean(covbal$x5_cbgps), 2), " (",
                                    min(covbal$x5_cbgps), ", ",
                                    max(covbal$x5_cbgps), ")"),
                             paste0(round(mean(covbal$x5_npcbgps), 2), " (",
                                    min(covbal$x5_npcbgps), ", ",
                                    max(covbal$x5_npcbgps), ")"),
                             NA,
                             NA,
                             NA,
                             NA,
                             paste0(round(mean(covbal$x5_olr), 2), " (",
                                    min(covbal$x5_olr), ", ",
                                    max(covbal$x5_olr), ")")),
               `Mean (min, max)     ` = c(paste0(round(mean(covbal$x6_uw), 2), " (",
                                    min(covbal$x6_uw), ", ",
                                    max(covbal$x6_uw), ")"),
                                  paste0(round(mean(covbal$x6_ols), 2), " (",
                                    min(covbal$x6_ols), ", ",
                                    max(covbal$x6_ols), ")"),
                             paste0(round(mean(covbal$x6_cbgps), 2), " (",
                                    min(covbal$x6_cbgps), ", ",
                                    max(covbal$x6_cbgps), ")"),
                             paste0(round(mean(covbal$x6_npcbgps), 2), " (",
                                    min(covbal$x6_npcbgps), ", ",
                                    max(covbal$x6_npcbgps), ")"),
                             NA,
                             NA,
                             NA,
                             NA,
                             paste0(round(mean(covbal$x6_olr), 2), " (",
                                    min(covbal$x6_olr), ", ",
                                    max(covbal$x6_olr), ")"))
               )
```

Table 2 - Inverse Probability Weight and Covariate Balance Distributions [Mean (Min, Max) Version]

```
fin_tab1 <- tibble(Method = c("Unweighted",
                              "Stabilized weight",
                              "Unbalanced covariates",
                          "Ordinary least squares",
                          "Stabilized weight",
                              "Unbalanced covariates",
                          "Covariate balancing generalized propensity score",
```

```
            "Stabilized weight",
                "Unbalanced covariates",
            "Non-parametric covariate balancing generalized propensity score",
            "Stabilized weight",
                "Unbalanced covariates",
            "Quantile binning categories",
            "10",
            "Stabilized weight",
                "Unbalanced covariates",
            "15",
            "Stabilized weight",
                "Unbalanced covariates",
            "20",
            "Stabilized weight",
                "Unbalanced covariates",
            "Ordinal logistic regression",
            "Stabilized weight",
                "Unbalanced covariates"),
    `Mean (min, max)` = c(NA, NA, covbal_tab[1, 2],
                          NA, tab2[1, 2], covbal_tab[2, 2],
                          NA, tab2[2, 2], covbal_tab[3, 2],
                          NA, tab2[3, 2], covbal_tab[4, 2],
                          NA,
                          NA, tab2[5, 2], covbal_tab[6, 2],
                          NA, tab2[6, 2], covbal_tab[7, 2],
                          NA, tab2[7, 2], covbal_tab[8, 2],
                          NA, tab2[8, 2], covbal_tab[9, 2]),
    `Mean (min, max)   ` = c(NA, NA, covbal_tab[1, 5],
                          NA, tab2[1, 5], covbal_tab[2, 5],
                          NA, tab2[2, 5], covbal_tab[3, 5],
                          NA, tab2[3, 5], covbal_tab[4, 5],
                          NA,
                          NA, tab2[5, 5], covbal_tab[6, 5],
                          NA, tab2[6, 5], covbal_tab[7, 5],
                          NA, tab2[7, 5], covbal_tab[8, 5],
                          NA, tab2[8, 5], covbal_tab[9, 5]),
    `Mean (min, max) ` = c(NA, NA, covbal_tab[1, 3],
                          NA, tab2[1, 3], covbal_tab[2, 3],
                          NA, tab2[2, 3], covbal_tab[3, 3],
                          NA, tab2[3, 3], covbal_tab[4, 3],
                          NA,
                          NA, tab2[5, 3], covbal_tab[6, 3],
                          NA, tab2[6, 3], covbal_tab[7, 3],
                          NA, tab2[7, 3], covbal_tab[8, 3],
                          NA, tab2[8, 3], covbal_tab[9, 3]),
    `Mean (min, max)    `  = c(NA, NA, covbal_tab[1, 6],
                          NA, tab2[1, 6], covbal_tab[2, 6],
                          NA, tab2[2, 6], covbal_tab[3, 6],
                          NA, tab2[3, 6], covbal_tab[4, 6],
                          NA,
                          NA, tab2[5, 6], covbal_tab[6, 6],
                          NA, tab2[6, 6], covbal_tab[7, 6],
                          NA, tab2[7, 6], covbal_tab[8, 6],
```

```
                                    NA, tab2[8, 6], covbal_tab[9, 6]),
                   `Mean (min, max)  ` = c(NA, NA, covbal_tab[1, 4],
                                    NA, tab2[1, 4], covbal_tab[2, 4],
                                    NA, tab2[2, 4], covbal_tab[3, 4],
                                    NA, tab2[3, 4], covbal_tab[4, 4],
                                    NA,
                                    NA, tab2[5, 4], covbal_tab[6, 4],
                                    NA, tab2[6, 4], covbal_tab[7, 4],
                                    NA, tab2[7, 4], covbal_tab[8, 4],
                                    NA, tab2[8, 4], covbal_tab[9, 4]),
                   `Mean (min, max)    `  = c(NA, NA, covbal_tab[1, 7],
                                    NA, tab2[1, 7], covbal_tab[2, 7],
                                    NA, tab2[2, 7], covbal_tab[3, 7],
                                    NA, tab2[3, 7], covbal_tab[4, 7],
                                    NA,
                                    NA, tab2[5, 7], covbal_tab[6, 7],
                                    NA, tab2[6, 7], covbal_tab[7, 7],
                                    NA, tab2[7, 7], covbal_tab[8, 7],
                                    NA, tab2[8, 7], covbal_tab[9, 7]))

kable(fin_tab1) %>%
  kable_classic(html_font = "Arial", full_width = FALSE) %>%
  add_header_above(c("Exposure", "X1" = 1, "X4" = 1, "X2" = 1, "X5" = 1,
                   "X3" = 1, "X6" = 1), bold = TRUE) %>%
  add_header_above(c("Marginally", "Normal" = 2, "Non-Normal" = 2,
                   "Non-Normal" = 2), bold = TRUE) %>%
  add_header_above(c("Conditionally", "Normal" = 2, "Normal" = 2,
                   "Non-Normal" = 2), bold = TRUE)  %>%
  add_indent(c(2:3, 5:6, 8:9, 11:12, 14:22, 24:25)) %>%
  add_indent(c(2:3, 5:6, 8:9, 11:12, 15:16, 18:19, 21:22, 24:25))
```

Assessment of Bias

Calculating Bias and Mean Squared Error

```
# will need to calculate all weights using x1 and x2 for each
  # simulated dataset with weighted lrm models
# then calculate bias for exposure coefficient versus truth

# create deciles quantiles for each Austin approach
x1_quants <- map_dbl(seq(0.1, 0.9, 0.1), ~ quantile(df$x1, .x))

x2_quants <- map_dbl(seq(0.1, 0.9, 0.1), ~ quantile(df$x2, .x))

x3_quants <- map_dbl(seq(0.1, 0.9, 0.1), ~ quantile(df$x3, .x))

x4_quants <- map_dbl(seq(0.1, 0.9, 0.1), ~ quantile(df$x4, .x))

x5_quants <- map_dbl(seq(0.1, 0.9, 0.1), ~ quantile(df$x5, .x))

x6_quants <- map_dbl(seq(0.1, 0.9, 0.1), ~ quantile(df$x6, .x))
```

```r
# function to get list of biases via msm approach and Austin approaches
bias_func <- function(data){
  # simulation number
  i <- data$i[1]

  # bias via the Marginal Structural Model Approach

  # generate weighted models
  # unweighted comparison
  x1_uw <- lrm(y1 ~ x1, data = data)
  x2_uw <- lrm(y2 ~ x2, data = data)
  x3_uw <- lrm(y3 ~ x3, data = data)
  x4_uw  <- lrm(y4 ~ x4, data = data)
  x5_uw  <- lrm(y5 ~ x5, data = data)
  x6_uw  <- lrm(y6 ~ x6, data = data)

  # ols
  d_ols_x1 <- svydesign(~1, weights = data$x1_ols_wts, data = data)
  x1_ols <- svyglm(y1 ~ x1, design = d_ols_x1, family = binomial)
  d_ols_x2 <- svydesign(~1, weights = data$x2_ols_wts, data = data)
  x2_ols <- svyglm(y2 ~ x2, design = d_ols_x2, family = binomial)
  d_ols_x3 <- svydesign(~1, weights = data$x3_ols_wts, data = data)
  x3_ols <- svyglm(y3 ~ x3, design = d_ols_x3, family = binomial)
  d_ols_x4 <- svydesign(~1, weights = data$x4_ols_wts, data = data)
  x4_ols <- svyglm(y4 ~ x4, design = d_ols_x4, family = binomial)
  d_ols_x5 <- svydesign(~1, weights = data$x5_ols_wts, data = data)
  x5_ols <- svyglm(y5 ~ x5, design = d_ols_x5, family = binomial)
  d_ols_x6 <- svydesign(~1, weights = data$x6_ols_wts, data = data)
  x6_ols <- svyglm(y6 ~ x6, design = d_ols_x6, family = binomial)

  # cbgps
  d_cbgps_x1 <- svydesign(~1, weights = data$x1_cbgps_wts, data = data)
  x1_cbgps <- svyglm(y1 ~ x1, design = d_cbgps_x1, family = binomial)
  d_cbgps_x2 <- svydesign(~1, weights = data$x2_cbgps_wts, data = data)
  x2_cbgps <- svyglm(y2 ~ x2, design = d_cbgps_x2, family = binomial)
  d_cbgps_x3 <- svydesign(~1, weights = data$x3_cbgps_wts, data = data)
  x3_cbgps <- svyglm(y3 ~ x3, design = d_cbgps_x3, family = binomial)
  d_cbgps_x4 <- svydesign(~1, weights = data$x4_cbgps_wts, data = data)
  x4_cbgps <- svyglm(y4 ~ x4, design = d_cbgps_x4, family = binomial)
  d_cbgps_x5 <- svydesign(~1, weights = data$x5_cbgps_wts, data = data)
  x5_cbgps <- svyglm(y5 ~ x5, design = d_cbgps_x5, family = binomial)
  d_cbgps_x6 <- svydesign(~1, weights = data$x6_cbgps_wts, data = data)
  x6_cbgps <- svyglm(y6 ~ x6, design = d_cbgps_x6, family = binomial)

  # npcbgps
  d_npcbgps_x1 <- svydesign(~1, weights = data$x1_npcbgps_wts, data = data)
  x1_npcbgps <- svyglm(y1 ~ x1, design = d_npcbgps_x1, family = binomial)
  d_npcbgps_x2 <- svydesign(~1, weights = data$x2_npcbgps_wts, data = data)
  x2_npcbgps <- svyglm(y2 ~ x2, design = d_npcbgps_x2, family = binomial)
  d_npcbgps_x3 <- svydesign(~1, weights = data$x3_npcbgps_wts, data = data)
  x3_npcbgps <- svyglm(y3 ~ x3, design = d_npcbgps_x3, family = binomial)
  d_npcbgps_x4 <- svydesign(~1, weights = data$x4_npcbgps_wts, data = data)
  x4_npcbgps <- svyglm(y4 ~ x4, design = d_npcbgps_x4, family = binomial)
```

```r
d_npcbgps_x5 <- svydesign(~1, weights = data$x5_npcbgps_wts, data = data)
x5_npcbgps <- svyglm(y5 ~ x5, design = d_npcbgps_x5, family = binomial)
d_npcbgps_x6 <- svydesign(~1, weights = data$x6_npcbgps_wts, data = data)
x6_npcbgps <- svyglm(y6 ~ x6, design = d_npcbgps_x6, family = binomial)

# qb10
d_qb10_x1 <- svydesign(~1, weights = data$x1_qb10_wts, data = data)
x1_qb10 <- svyglm(y1 ~ x1, design = d_qb10_x1, family = binomial)
d_qb10_x2 <- svydesign(~1, weights = data$x2_qb10_wts, data = data)
x2_qb10 <- svyglm(y2 ~ x2, design = d_qb10_x2, family = binomial)
d_qb10_x3 <- svydesign(~1, weights = data$x3_qb10_wts, data = data)
x3_qb10 <- svyglm(y3 ~ x3, design = d_qb10_x3, family = binomial)

# qb15
d_qb15_x1 <- svydesign(~1, weights = data$x1_qb15_wts, data = data)
x1_qb15 <- svyglm(y1 ~ x1, design = d_qb15_x1, family = binomial)
d_qb15_x2 <- svydesign(~1, weights = data$x2_qb15_wts, data = data)
x2_qb15 <- svyglm(y2 ~ x2, design = d_qb15_x2, family = binomial)
d_qb15_x3 <- svydesign(~1, weights = data$x3_qb15_wts, data = data)
x3_qb15 <- svyglm(y3 ~ x3, design = d_qb15_x3, family = binomial)

# qb20
d_qb20_x1 <- svydesign(~1, weights = data$x1_qb20_wts, data = data)
x1_qb20 <- svyglm(y1 ~ x1, design = d_qb20_x1, family = binomial)
d_qb20_x2 <- svydesign(~1, weights = data$x2_qb20_wts, data = data)
x2_qb20 <- svyglm(y2 ~ x2, design = d_qb20_x2, family = binomial)
d_qb20_x3 <- svydesign(~1, weights = data$x3_qb20_wts, data = data)
x3_qb20 <- svyglm(y3 ~ x3, design = d_qb20_x3, family = binomial)

# olr
d_olr_x1 <- svydesign(~1, weights = data$x1_olr_wts, data = data)
x1_olr <- svyglm(y1 ~ x1, design = d_olr_x1, family = binomial)
d_olr_x2 <- svydesign(~1, weights = data$x2_olr_wts, data = data)
x2_olr <- svyglm(y2 ~ x2, design = d_olr_x2, family = binomial)
d_olr_x3 <- svydesign(~1, weights = data$x3_olr_wts, data = data)
x3_olr <- svyglm(y3 ~ x3, design = d_olr_x3, family = binomial)
d_olr_x4 <- svydesign(~1, weights = data$x4_olr_wts, data = data)
x4_olr <- svyglm(y4 ~ x4, design = d_olr_x4, family = binomial)
d_olr_x5 <- svydesign(~1, weights = data$x5_olr_wts, data = data)
x5_olr <- svyglm(y5 ~ x5, design = d_olr_x5, family = binomial)
d_olr_x6 <- svydesign(~1, weights = data$x6_olr_wts, data = data)
x6_olr <- svyglm(y6 ~ x6, design = d_olr_x6, family = binomial)

# bias via the Marginal Structural Model Approach

# unweighted bias
x1_uw_bias <- true_x1 - x1_uw$coefficient[2]
x2_uw_bias <- true_x2 - x2_uw$coefficient[2]
x3_uw_bias <- true_x3 - x3_uw$coefficient[2]
x4_uw_bias <- true_x4 - x4_uw$coefficient[2]
x5_uw_bias <- true_x5 - x5_uw$coefficient[2]
x6_uw_bias <- true_x6 - x6_uw$coefficient[2]
```

```
# unweighted se
x1_uw_se <- sqrt(x1_uw$var[2,2])
x2_uw_se <- sqrt(x2_uw$var[2,2])
x3_uw_se <- sqrt(x3_uw$var[2,2])
x4_uw_se <- sqrt(x4_uw$var[2,2])
x5_uw_se <- sqrt(x5_uw$var[2,2])
x6_uw_se <- sqrt(x6_uw$var[2,2])

# unweighted coverage
x1_uw_cov <- (true_x1 > (x1_uw$coefficient[2] - (1.96 * x1_uw_se))) &
  (true_x1 < (x1_uw$coefficient[2] + (1.96 * x1_uw_se)))
x2_uw_cov <- (true_x2 > (x2_uw$coefficient[2] - (1.96 * x2_uw_se))) &
  (true_x2 < (x2_uw$coefficient[2] + (1.96 * x2_uw_se)))
x3_uw_cov <- (true_x3 > (x3_uw$coefficient[2] - (1.96 * x3_uw_se))) &
  (true_x3 < (x3_uw$coefficient[2] + (1.96 * x3_uw_se)))
x4_uw_cov <- (true_x4 > (x4_uw$coefficient[2] - (1.96 * x4_uw_se))) &
  (true_x4 < (x4_uw$coefficient[2] + (1.96 * x4_uw_se)))
x5_uw_cov <- (true_x5 > (x5_uw$coefficient[2] - (1.96 * x5_uw_se))) &
  (true_x5 < (x5_uw$coefficient[2] + (1.96 * x5_uw_se)))
x6_uw_cov <- (true_x6 > (x6_uw$coefficient[2] - (1.96 * x6_uw_se))) &
  (true_x6 < (x6_uw$coefficient[2] + (1.96 * x6_uw_se)))

# ols
x1_ols_bias <- true_x1 - x1_ols$coefficient[2]
x2_ols_bias <- true_x2 - x2_ols$coefficient[2]
x3_ols_bias <- true_x3 - x3_ols$coefficient[2]
x4_ols_bias <- true_x4 - x4_ols$coefficient[2]
x5_ols_bias <- true_x5 - x5_ols$coefficient[2]
x6_ols_bias <- true_x6 - x6_ols$coefficient[2]

# ols se
x1_ols_se <- sqrt(x1_ols$cov.unscaled[2,2])
x2_ols_se <- sqrt(x2_ols$cov.unscaled[2,2])
x3_ols_se <- sqrt(x3_ols$cov.unscaled[2,2])
x4_ols_se <- sqrt(x4_ols$cov.unscaled[2,2])
x5_ols_se <- sqrt(x5_ols$cov.unscaled[2,2])
x6_ols_se <- sqrt(x6_ols$cov.unscaled[2,2])

# ols coverage
x1_ols_cov <- (true_x1 > (x1_ols$coefficient[2] - (1.96 * x1_ols_se))) &
  (true_x1 < (x1_ols$coefficient[2] + (1.96 * x1_ols_se)))
x2_ols_cov <- (true_x2 > (x2_ols$coefficient[2] - (1.96 * x2_ols_se))) &
  (true_x2 < (x2_ols$coefficient[2] + (1.96 * x2_ols_se)))
x3_ols_cov <- (true_x3 > (x3_ols$coefficient[2] - (1.96 * x3_ols_se))) &
  (true_x3 < (x3_ols$coefficient[2] + (1.96 * x3_ols_se)))
x4_ols_cov <- (true_x4 > (x4_ols$coefficient[2] - (1.96 * x4_ols_se))) &
  (true_x4 < (x4_ols$coefficient[2] + (1.96 * x4_ols_se)))
x5_ols_cov <- (true_x5 > (x5_ols$coefficient[2] - (1.96 * x5_ols_se))) &
  (true_x5 < (x5_ols$coefficient[2] + (1.96 * x5_ols_se)))
x6_ols_cov <- (true_x6 > (x6_ols$coefficient[2] - (1.96 * x6_ols_se))) &
  (true_x6 < (x6_ols$coefficient[2] + (1.96 * x6_ols_se)))

# cbgps
```

```
x1_cbgps_bias <- true_x1 - x1_cbgps$coefficient[2]
x2_cbgps_bias <- true_x2 - x2_cbgps$coefficient[2]
x3_cbgps_bias <- true_x3 - x3_cbgps$coefficient[2]
x4_cbgps_bias <- true_x4 - x4_cbgps$coefficient[2]
x5_cbgps_bias <- true_x5 - x5_cbgps$coefficient[2]
x6_cbgps_bias <- true_x6 - x6_cbgps$coefficient[2]

# cbgps se
x1_cbgps_se <- sqrt(x1_cbgps$cov.unscaled[2,2])
x2_cbgps_se <- sqrt(x2_cbgps$cov.unscaled[2,2])
x3_cbgps_se <- sqrt(x3_cbgps$cov.unscaled[2,2])
x4_cbgps_se <- sqrt(x4_cbgps$cov.unscaled[2,2])
x5_cbgps_se <- sqrt(x5_cbgps$cov.unscaled[2,2])
x6_cbgps_se <- sqrt(x6_cbgps$cov.unscaled[2,2])

# cbgps coverage
x1_cbgps_cov <- (true_x1 > (x1_cbgps$coefficient[2] - (1.96 * x1_cbgps_se))) &
  (true_x1 < (x1_cbgps$coefficient[2] + (1.96 * x1_cbgps_se)))
x2_cbgps_cov <- (true_x2 > (x2_cbgps$coefficient[2] - (1.96 * x2_cbgps_se))) &
  (true_x2 < (x2_cbgps$coefficient[2] + (1.96 * x2_cbgps_se)))
x3_cbgps_cov <- (true_x3 > (x3_cbgps$coefficient[2] - (1.96 * x3_cbgps_se))) &
  (true_x3 < (x3_cbgps$coefficient[2] + (1.96 * x3_cbgps_se)))
x4_cbgps_cov <- (true_x4 > (x4_cbgps$coefficient[2] - (1.96 * x4_cbgps_se))) &
  (true_x4 < (x4_cbgps$coefficient[2] + (1.96 * x4_cbgps_se)))
x5_cbgps_cov <- (true_x5 > (x5_cbgps$coefficient[2] - (1.96 * x5_cbgps_se))) &
  (true_x5 < (x5_cbgps$coefficient[2] + (1.96 * x5_cbgps_se)))
x6_cbgps_cov <- (true_x6 > (x6_cbgps$coefficient[2] - (1.96 * x6_cbgps_se))) &
  (true_x6 < (x6_cbgps$coefficient[2] + (1.96 * x6_cbgps_se)))

# npcbgps
x1_npcbgps_bias <- true_x1 - x1_npcbgps$coefficient[2]
x2_npcbgps_bias <- true_x2 - x2_npcbgps$coefficient[2]
x3_npcbgps_bias <- true_x3 - x3_npcbgps$coefficient[2]
x4_npcbgps_bias <- true_x4 - x4_npcbgps$coefficient[2]
x5_npcbgps_bias <- true_x5 - x5_npcbgps$coefficient[2]
x6_npcbgps_bias <- true_x6 - x6_npcbgps$coefficient[2]

# npcbgps se
x1_npcbgps_se <- sqrt(x1_npcbgps$cov.unscaled[2,2])
x2_npcbgps_se <- sqrt(x2_npcbgps$cov.unscaled[2,2])
x3_npcbgps_se <- sqrt(x3_npcbgps$cov.unscaled[2,2])
x4_npcbgps_se <- sqrt(x4_npcbgps$cov.unscaled[2,2])
x5_npcbgps_se <- sqrt(x5_npcbgps$cov.unscaled[2,2])
x6_npcbgps_se <- sqrt(x6_npcbgps$cov.unscaled[2,2])

# npcbgps coverage
x1_npcbgps_cov <- (true_x1 > (x1_npcbgps$coefficient[2] - (1.96 * x1_npcbgps_se))) &
  (true_x1 < (x1_npcbgps$coefficient[2] + (1.96 * x1_npcbgps_se)))
x2_npcbgps_cov <- (true_x2 > (x2_npcbgps$coefficient[2] - (1.96 * x2_npcbgps_se))) &
  (true_x2 < (x2_npcbgps$coefficient[2] + (1.96 * x2_npcbgps_se)))
x3_npcbgps_cov <- (true_x3 > (x3_npcbgps$coefficient[2] - (1.96 * x3_npcbgps_se))) &
  (true_x3 < (x3_npcbgps$coefficient[2] + (1.96 * x3_npcbgps_se)))
x4_npcbgps_cov <- (true_x4 > (x4_npcbgps$coefficient[2] - (1.96 * x4_npcbgps_se))) &
```

```
  (true_x4 < (x4_npcbgps$coefficient[2] + (1.96 * x4_npcbgps_se)))
x5_npcbgps_cov <- (true_x5 > (x5_npcbgps$coefficient[2] - (1.96 * x5_npcbgps_se))) &
  (true_x5 < (x5_npcbgps$coefficient[2] + (1.96 * x5_npcbgps_se)))
x6_npcbgps_cov <- (true_x6 > (x6_npcbgps$coefficient[2] - (1.96 * x6_npcbgps_se))) &
  (true_x6 < (x6_npcbgps$coefficient[2] + (1.96 * x6_npcbgps_se)))

# qb10
x1_qb10_bias <- true_x1 - x1_qb10$coefficient[2]
x2_qb10_bias <- true_x2 - x2_qb10$coefficient[2]
x3_qb10_bias <- true_x3 - x3_qb10$coefficient[2]

# qb10 se
x1_qb10_se <- sqrt(x1_qb10$cov.unscaled[2,2])
x2_qb10_se <- sqrt(x2_qb10$cov.unscaled[2,2])
x3_qb10_se <- sqrt(x3_qb10$cov.unscaled[2,2])

# qb10 coverage
x1_qb10_cov <- (true_x1 > (x1_qb10$coefficient[2] - (1.96 * x1_qb10_se))) &
  (true_x1 < (x1_qb10$coefficient[2] + (1.96 * x1_qb10_se)))
x2_qb10_cov <- (true_x2 > (x2_qb10$coefficient[2] - (1.96 * x2_qb10_se))) &
  (true_x2 < (x2_qb10$coefficient[2] + (1.96 * x2_qb10_se)))
x3_qb10_cov <- (true_x3 > (x3_qb10$coefficient[2] - (1.96 * x3_qb10_se))) &
  (true_x3 < (x3_qb10$coefficient[2] + (1.96 * x3_qb10_se)))

# qb15
x1_qb15_bias <- true_x1 - x1_qb15$coefficient[2]
x2_qb15_bias <- true_x2 - x2_qb15$coefficient[2]
x3_qb15_bias <- true_x3 - x3_qb15$coefficient[2]

#qb15 se
x1_qb15_se <- sqrt(x1_qb15$cov.unscaled[2,2])
x2_qb15_se <- sqrt(x2_qb15$cov.unscaled[2,2])
x3_qb15_se <- sqrt(x3_qb15$cov.unscaled[2,2])

#_qb15 coverage
x1_qb15_cov <- (true_x1 > (x1_qb15$coefficient[2] - (1.96 * x1_qb15_se))) &
  (true_x1 < (x1_qb15$coefficient[2] + (1.96 * x1_qb15_se)))
x2_qb15_cov <- (true_x2 > (x2_qb15$coefficient[2] - (1.96 * x2_qb15_se))) &
  (true_x2 < (x2_qb15$coefficient[2] + (1.96 * x2_qb15_se)))
x3_qb15_cov <- (true_x3 > (x3_qb15$coefficient[2] - (1.96 * x3_qb15_se))) &
  (true_x3 < (x3_qb15$coefficient[2] + (1.96 * x3_qb15_se)))

# qb20
x1_qb20_bias <- true_x1 - x1_qb20$coefficient[2]
x2_qb20_bias <- true_x2 - x2_qb20$coefficient[2]
x3_qb20_bias <- true_x3 - x3_qb20$coefficient[2]

#qb20 se
x1_qb20_se <- sqrt(x1_qb20$cov.unscaled[2,2])
x2_qb20_se <- sqrt(x2_qb20$cov.unscaled[2,2])
x3_qb20_se <- sqrt(x3_qb20$cov.unscaled[2,2])

#_qb20 coverage
```

```
x1_qb20_cov <- (true_x1 > (x1_qb20$coefficient[2] - (1.96 * x1_qb20_se))) &
  (true_x1 < (x1_qb20$coefficient[2] + (1.96 * x1_qb20_se)))
x2_qb20_cov <- (true_x2 > (x2_qb20$coefficient[2] - (1.96 * x2_qb20_se))) &
  (true_x2 < (x2_qb20$coefficient[2] + (1.96 * x2_qb20_se)))
x3_qb20_cov <- (true_x3 > (x3_qb20$coefficient[2] - (1.96 * x3_qb20_se))) &
  (true_x3 < (x3_qb20$coefficient[2] + (1.96 * x3_qb20_se)))

# olr
x1_olr_bias <- true_x1 - x1_olr$coefficient[2]
x2_olr_bias <- true_x2 - x2_olr$coefficient[2]
x3_olr_bias <- true_x3 - x3_olr$coefficient[2]
x4_olr_bias <- true_x4 - x4_olr$coefficient[2]
x5_olr_bias <- true_x5 - x5_olr$coefficient[2]
x6_olr_bias <- true_x6 - x6_olr$coefficient[2]

# olr se
x1_olr_se <- sqrt(x1_olr$cov.unscaled[2,2])
x2_olr_se <- sqrt(x2_olr$cov.unscaled[2,2])
x3_olr_se <- sqrt(x3_olr$cov.unscaled[2,2])
x4_olr_se <- sqrt(x4_olr$cov.unscaled[2,2])
x5_olr_se <- sqrt(x5_olr$cov.unscaled[2,2])
x6_olr_se <- sqrt(x6_olr$cov.unscaled[2,2])

# olr coverage
x1_olr_cov <- (true_x1 > (x1_olr$coefficient[2] - (1.96 * x1_olr_se))) &
  (true_x1 < (x1_olr$coefficient[2] + (1.96 * x1_olr_se)))
x2_olr_cov <- (true_x2 > (x2_olr$coefficient[2] - (1.96 * x2_olr_se))) &
  (true_x2 < (x2_olr$coefficient[2] + (1.96 * x2_olr_se)))
x3_olr_cov <- (true_x3 > (x3_olr$coefficient[2] - (1.96 * x3_olr_se))) &
  (true_x3 < (x3_olr$coefficient[2] + (1.96 * x3_olr_se)))
x4_olr_cov <- (true_x4 > (x4_olr$coefficient[2] - (1.96 * x4_olr_se))) &
  (true_x4 < (x4_olr$coefficient[2] + (1.96 * x4_olr_se)))
x5_olr_cov <- (true_x5 > (x5_olr$coefficient[2] - (1.96 * x5_olr_se))) &
  (true_x5 < (x5_olr$coefficient[2] + (1.96 * x5_olr_se)))
x6_olr_cov <- (true_x6 > (x6_olr$coefficient[2] - (1.96 * x6_olr_se))) &
  (true_x6 < (x6_olr$coefficient[2] + (1.96 * x6_olr_se)))

# bias via the Austin, 2018 approach

# first have to generate probability of having each exposure decile in each model

# unweighted
x1_uw_qs <- map_dbl(x1_quants,
                 ~ predict(x1_uw,
                           newdata = .x,
                           type = "fitted"))
x2_uw_qs <- map_dbl(x2_quants,
                 ~ predict(x2_uw,
                           newdata = .x,
                           type = "fitted"))
x3_uw_qs <- map_dbl(x3_quants,
                 ~ predict(x3_uw,
                           newdata = .x,
```

```
                             type = "fitted"))
x4_uw_qs <- map_dbl(x4_quants,
                    ~ predict(x4_uw,
                              newdata = .x,
                              type = "fitted"))
x5_uw_qs <- map_dbl(x5_quants,
                    ~ predict(x5_uw,
                              newdata = .x,
                              type = "fitted"))
x6_uw_qs <- map_dbl(x6_quants,
                    ~ predict(x6_uw,
                              newdata = .x,
                              type = "fitted"))

# x1
x1_uw_bias2 <- true2_x1_qs - x1_uw_qs

# x2
x2_uw_bias2 <- true2_x2_qs - x2_uw_qs

# x3
x3_uw_bias2 <- true2_x3_qs - x3_uw_qs

# x4
x4_uw_bias2 <- true2_x4_qs - x4_uw_qs

# x5
x5_uw_bias2 <- true2_x5_qs - x5_uw_qs

# x6
x6_uw_bias2 <- true2_x6_qs - x6_uw_qs

  # ols
x1_ols_qs <- data.frame(predict(x1_ols,
                                newdata = data.frame(x1 = x1_quants),
                                type = "response"))$response
x2_ols_qs <- data.frame(predict(x2_ols,
                                newdata = data.frame(x2 = x2_quants),
                                type = "response"))$response
x3_ols_qs <- data.frame(predict(x3_ols,
                                newdata = data.frame(x3 = x3_quants),
                                type = "response"))$response
x4_ols_qs <- data.frame(predict(x4_ols,
                                newdata = data.frame(x4 = x4_quants),
                                type = "response"))$response
x5_ols_qs <- data.frame(predict(x5_ols,
                                newdata = data.frame(x5 = x5_quants),
                                type = "response"))$response
x6_ols_qs <- data.frame(predict(x6_ols,
                                newdata = data.frame(x6 = x6_quants),
                                type = "response"))$response

# x1
```

```
x1_ols_bias2 <- true2_x1_qs - x1_ols_qs

# x2
x2_ols_bias2 <- true2_x2_qs - x2_ols_qs

# x3
x3_ols_bias2 <- true2_x3_qs - x3_ols_qs

# x4
x4_ols_bias2 <- true2_x4_qs - x4_ols_qs

# x5
x5_ols_bias2 <- true2_x5_qs - x5_ols_qs

# x6
x6_ols_bias2 <- true2_x6_qs - x6_ols_qs

# cbgps
x1_cbgps_qs <- data.frame(predict(x1_cbgps,
                                  newdata = data.frame(x1 = x1_quants),
                                  type = "response"))$response
x2_cbgps_qs <- data.frame(predict(x2_cbgps,
                                  newdata = data.frame(x2 = x2_quants),
                                  type = "response"))$response
x3_cbgps_qs <- data.frame(predict(x3_cbgps,
                                  newdata = data.frame(x3 = x3_quants),
                                  type = "response"))$response
x4_cbgps_qs <- data.frame(predict(x4_cbgps,
                                  newdata = data.frame(x4 = x4_quants),
                                  type = "response"))$response
x5_cbgps_qs <- data.frame(predict(x5_cbgps,
                                  newdata = data.frame(x5 = x5_quants),
                                  type = "response"))$response
x6_cbgps_qs <- data.frame(predict(x6_cbgps,
                                  newdata = data.frame(x6 = x6_quants),
                                  type = "response"))$response

# x1
x1_cbgps_bias2 <- true2_x1_qs - x1_cbgps_qs

# x2
x2_cbgps_bias2 <- true2_x2_qs - x2_cbgps_qs

# x3
x3_cbgps_bias2 <- true2_x3_qs - x3_cbgps_qs

# x4
x4_cbgps_bias2 <- true2_x4_qs - x4_cbgps_qs

# x5
x5_cbgps_bias2 <- true2_x5_qs - x5_cbgps_qs

# x6
```

```
x6_cbgps_bias2 <- true2_x6_qs - x6_cbgps_qs

# npcbgps
x1_npcbgps_qs <- data.frame(predict(x1_npcbgps,
                                    newdata = data.frame(x1 = x1_quants),
                                    type = "response"))$response
x2_npcbgps_qs <- data.frame(predict(x2_npcbgps,
                                    newdata = data.frame(x2 = x2_quants),
                                    type = "response"))$response
x3_npcbgps_qs <- data.frame(predict(x3_npcbgps,
                                    newdata = data.frame(x3 = x3_quants),
                                    type = "response"))$response
x4_npcbgps_qs <- data.frame(predict(x4_npcbgps,
                                    newdata = data.frame(x4 = x4_quants),
                                    type = "response"))$response
x5_npcbgps_qs <- data.frame(predict(x5_npcbgps,
                                    newdata = data.frame(x5 = x5_quants),
                                    type = "response"))$response
x6_npcbgps_qs <- data.frame(predict(x6_npcbgps,
                                    newdata = data.frame(x6 = x6_quants),
                                    type = "response"))$response

# x1
x1_npcbgps_bias2 <- true2_x1_qs - x1_npcbgps_qs

# x2
x2_npcbgps_bias2 <- true2_x2_qs - x2_npcbgps_qs

# x3
x3_npcbgps_bias2 <- true2_x3_qs - x3_npcbgps_qs

# x4
x4_npcbgps_bias2 <- true2_x4_qs - x4_npcbgps_qs

# x5
x5_npcbgps_bias2 <- true2_x5_qs - x5_npcbgps_qs

# x6
x6_npcbgps_bias2 <- true2_x6_qs - x6_npcbgps_qs

# qb10
x1_qb10_qs <- data.frame(predict(x1_qb10,
                                    newdata = data.frame(x1 = x1_quants),
                                    type = "response"))$response
x2_qb10_qs <- data.frame(predict(x2_qb10,
                                    newdata = data.frame(x2 = x2_quants),
                                    type = "response"))$response
x3_qb10_qs <- data.frame(predict(x3_qb10,
                                    newdata = data.frame(x3 = x3_quants),
                                    type = "response"))$response

# x1
x1_qb10_bias2 <- true2_x1_qs - x1_qb10_qs
```

```
# x2
x2_qb10_bias2 <- true2_x2_qs - x2_qb10_qs

# x3
x3_qb10_bias2 <- true2_x3_qs - x3_qb10_qs

# qb15
x1_qb15_qs <- data.frame(predict(x1_qb15,
                                 newdata = data.frame(x1 = x1_quants),
                                 type = "response"))$response
x2_qb15_qs <- data.frame(predict(x2_qb15,
                                 newdata = data.frame(x2 = x2_quants),
                                 type = "response"))$response
x3_qb15_qs <- data.frame(predict(x3_qb15,
                                 newdata = data.frame(x3 = x3_quants),
                                 type = "response"))$response

# x1
x1_qb15_bias2 <- true2_x1_qs - x1_qb15_qs

# x2
x2_qb15_bias2 <- true2_x2_qs - x2_qb15_qs

# x3
x3_qb15_bias2 <- true2_x3_qs - x3_qb15_qs

# qb20
x1_qb20_qs <- data.frame(predict(x1_qb20,
                                 newdata = data.frame(x1 = x1_quants),
                                 type = "response"))$response
x2_qb20_qs <- data.frame(predict(x2_qb20,
                                 newdata = data.frame(x2 = x2_quants),
                                 type = "response"))$response
x3_qb20_qs <- data.frame(predict(x3_qb20,
                                 newdata = data.frame(x3 = x3_quants),
                                 type = "response"))$response

# x1
x1_qb20_bias2 <- true2_x1_qs - x1_qb20_qs

# x2
x2_qb20_bias2 <- true2_x2_qs - x2_qb20_qs

# x3
x3_qb20_bias2 <- true2_x3_qs - x3_qb20_qs

# olr
x1_olr_qs <- data.frame(predict(x1_olr,
                                newdata = data.frame(x1 = x1_quants),
                                type = "response"))$response
x2_olr_qs <- data.frame(predict(x2_olr,
                                newdata = data.frame(x2 = x2_quants),
                                type = "response"))$response
```

```
x3_olr_qs <- data.frame(predict(x3_olr,
                                newdata = data.frame(x3 = x3_quants),
                                type = "response"))$response
x4_olr_qs <- data.frame(predict(x4_olr,
                                newdata = data.frame(x4 = x4_quants),
                                type = "response"))$response
x5_olr_qs <- data.frame(predict(x5_olr,
                                newdata = data.frame(x5 = x5_quants),
                                type = "response"))$response
x6_olr_qs <- data.frame(predict(x6_olr,
                                newdata = data.frame(x6 = x6_quants),
                                type = "response"))$response

# x1
x1_olr_bias2 <- true2_x1_qs - x1_olr_qs

# x2
x2_olr_bias2 <- true2_x2_qs - x2_olr_qs

# x3
x3_olr_bias2 <- true2_x3_qs - x3_olr_qs

# x4
x4_olr_bias2 <- true2_x4_qs - x4_olr_qs

# x5
x5_olr_bias2 <- true2_x5_qs - x5_olr_qs

# x6
x6_olr_bias2 <- true2_x6_qs - x6_olr_qs

# output dataframe
bias1 <- data.frame(i,
           x1_uw_bias, x2_uw_bias, x3_uw_bias, x4_uw_bias, x5_uw_bias, x6_uw_bias,
           x1_ols_bias, x2_ols_bias, x3_ols_bias, x4_ols_bias, x5_ols_bias, x6_ols_bias,
           x1_cbgps_bias, x2_cbgps_bias, x3_cbgps_bias, x4_cbgps_bias, x5_cbgps_bias, x6_cbgps_bias,
           x1_npcbgps_bias, x2_npcbgps_bias, x3_npcbgps_bias, x4_npcbgps_bias, x5_npcbgps_bias, x6_np
           x1_qb10_bias, x2_qb10_bias, x3_qb10_bias,
           x1_qb15_bias, x2_qb15_bias, x3_qb15_bias,
           x1_qb20_bias, x2_qb20_bias, x3_qb20_bias,
           x1_olr_bias, x2_olr_bias, x3_olr_bias, x4_olr_bias, x5_olr_bias, x6_olr_bias)

se1 <- data.frame(i,
           x1_uw_se, x2_uw_se, x3_uw_se, x4_uw_se, x5_uw_se, x6_uw_se,
           x1_ols_se, x2_ols_se, x3_ols_se, x4_ols_se, x5_ols_se, x6_ols_se,
           x1_cbgps_se, x2_cbgps_se, x3_cbgps_se, x4_cbgps_se, x5_cbgps_se, x6_cbgps_se,
           x1_npcbgps_se, x2_npcbgps_se, x3_npcbgps_se, x4_npcbgps_se, x5_npcbgps_se, x6_npcbgps_se,
           x1_qb10_se, x2_qb10_se, x3_qb10_se,
           x1_qb15_se, x2_qb15_se, x3_qb15_se,
           x1_qb20_se, x2_qb20_se, x3_qb20_se,
           x1_olr_se, x2_olr_se, x3_olr_se, x4_olr_se, x5_olr_se, x6_olr_se)

cov1 <- data.frame(i,
```

```
             x1_uw_cov, x2_uw_cov, x3_uw_cov, x4_uw_cov, x5_uw_cov, x6_uw_cov,
             x1_ols_cov, x2_ols_cov, x3_ols_cov, x4_ols_cov, x5_ols_cov, x6_ols_cov,
             x1_cbgps_cov, x2_cbgps_cov, x3_cbgps_cov, x4_cbgps_cov, x5_cbgps_cov, x6_cbgps_cov,
             x1_npcbgps_cov, x2_npcbgps_cov, x3_npcbgps_cov, x4_npcbgps_cov, x5_npcbgps_cov, x6_npcbgps_
             x1_qb10_cov, x2_qb10_cov, x3_qb10_cov,
             x1_qb15_cov, x2_qb15_cov, x3_qb15_cov,
             x1_qb20_cov, x2_qb20_cov, x3_qb20_cov,
             x1_olr_cov, x2_olr_cov, x3_olr_cov, x4_olr_cov, x5_olr_cov, x6_olr_cov)

  bias2 <- data.frame(quantile = c(1:9),
             x1_uw_bias2, x2_uw_bias2, x3_uw_bias2, x4_uw_bias2, x5_uw_bias2, x6_uw_bias2,
             x1_ols_bias2, x2_ols_bias2, x3_ols_bias2, x4_ols_bias2, x5_ols_bias2, x6_ols_bias2,
             x1_cbgps_bias2, x2_cbgps_bias2, x3_cbgps_bias2, x4_cbgps_bias2, x5_cbgps_bias2, x6_cbgps_bi
             x1_npcbgps_bias2, x2_npcbgps_bias2, x3_npcbgps_bias2, x4_npcbgps_bias2, x5_npcbgps_bias2, 
             x1_qb10_bias2, x2_qb10_bias2, x3_qb10_bias2,
             x1_qb15_bias2, x2_qb15_bias2, x3_qb15_bias2,
             x1_qb20_bias2, x2_qb20_bias2, x3_qb20_bias2,
             x1_olr_bias2, x2_olr_bias2, x3_olr_bias2, x4_olr_bias2, x5_olr_bias2, x6_olr_bias2) %>%
    pivot_wider(names_from = quantile,
                values_from = x1_uw_bias2:x6_olr_bias2)

  data.frame(bias1, se1, cov1, bias2)
}

# # get bias across all simulations
# bias <- map_df(sims, ~ bias_func(.x))

# run in parallel with furrr
plan(multisession, workers = 7)
bias <- future_map_dfr(sims, ~ bias_func(.x))
Save(bias)
```

Dose Reponse Decile Approach

Web Figure 5 - Bias at Deciles

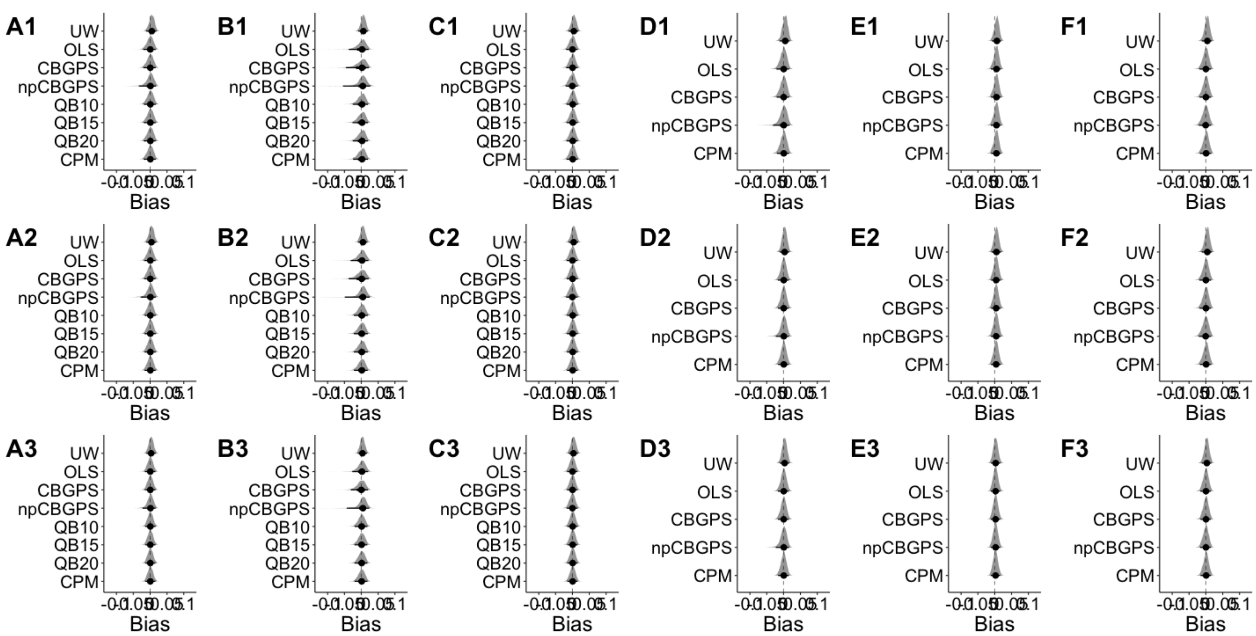
```
Load(bias)
# function to plot austin bias plots
aus_bias_plot <- function(decile) {
  # make bias dataframes
  x1_bias2 <- bias %>%
    select(starts_with("x1") & contains("bias2") & ends_with(as.character(decile))) %>%
    gather(label, bias) %>%
    mutate(label = factor(label,
                          levels = c(paste0("x1_uw_bias2_", decile),
                                     paste0("x1_ols_bias2_", decile),
                                     paste0("x1_cbgps_bias2_", decile),
                                     paste0("x1_npcbgps_bias2_", decile),
                                     paste0("x1_qb10_bias2_", decile),
                                     paste0("x1_qb15_bias2_", decile),
                                     paste0("x1_qb20_bias2_", decile),
                                     paste0("x1_olr_bias2_", decile))))
```

```
x2_bias2 <- bias %>%
  select(starts_with("x2") & contains("bias2") & ends_with(as.character(decile))) %>%
  gather(label, bias) %>%
  mutate(label = factor(label,
                        levels = c(paste0("x2_uw_bias2_", decile),
                                   paste0("x2_ols_bias2_", decile),
                                   paste0("x2_cbgps_bias2_", decile),
                                   paste0("x2_npcbgps_bias2_", decile),
                                   paste0("x2_qb10_bias2_", decile),
                                   paste0("x2_qb15_bias2_", decile),
                                   paste0("x2_qb20_bias2_", decile),
                                   paste0("x2_olr_bias2_", decile))))

x3_bias2 <- bias %>%
  select(starts_with("x3") & contains("bias2") & ends_with(as.character(decile))) %>%
  gather(label, bias) %>%
  mutate(label = factor(label,
                        levels = c(paste0("x3_uw_bias2_", decile),
                                   paste0("x3_ols_bias2_", decile),
                                   paste0("x3_cbgps_bias2_", decile),
                                   paste0("x3_npcbgps_bias2_", decile),
                                   paste0("x3_qb10_bias2_", decile),
                                   paste0("x3_qb15_bias2_", decile),
                                   paste0("x3_qb20_bias2_", decile),
                                   paste0("x3_olr_bias2_", decile))))

x4_bias2 <- bias %>%
  select(starts_with("x4") & contains("bias2") & ends_with(as.character(decile))) %>%
  gather(label, bias) %>%
  mutate(label = factor(label,
                        levels = c(paste0("x4_uw_bias2_", decile),
                                   paste0("x4_ols_bias2_", decile),
                                   paste0("x4_cbgps_bias2_", decile),
                                   paste0("x4_npcbgps_bias2_", decile),
                                   paste0("x4_olr_bias2_", decile))))

x5_bias2 <- bias %>%
  select(starts_with("x5") & contains("bias2") & ends_with(as.character(decile))) %>%
  gather(label, bias) %>%
  mutate(label = factor(label,
                        levels = c(paste0("x5_uw_bias2_", decile),
                                   paste0("x5_ols_bias2_", decile),
                                   paste0("x5_cbgps_bias2_", decile),
                                   paste0("x5_npcbgps_bias2_", decile),
                                   paste0("x5_olr_bias2_", decile))))

x6_bias2 <- bias %>%
  select(starts_with("x6") & contains("bias2") & ends_with(as.character(decile))) %>%
  gather(label, bias) %>%
  mutate(label = factor(label,
                        levels = c(paste0("x6_uw_bias2_", decile),
                                   paste0("x6_ols_bias2_", decile),
                                   paste0("x6_cbgps_bias2_", decile),
```

```
                                      paste0("x6_npcbgps_bias2_", decile),
                                      paste0("x6_olr_bias2_", decile))))

# make plots
x1_bias_plot2 <- ggplot(x1_bias2, aes(y = fct_rev(label), x = bias)) +
  stat_halfeye() +
  geom_vline(xintercept = 0, alpha = 0.5, linetype = "dashed") +
  scale_y_discrete(name = "", labels = c("CPM", "QB20", "QB15", "QB10", "npCBGPS", "CBGPS", "OLS", "UW
  scale_x_continuous(name = "Bias", limits = c(-0.125, 0.125),
                     breaks = seq(-0.1, 0.1, 0.05), labels = seq(-0.1, 0.1, 0.05)) +
  theme +
  theme(axis.text = element_text(size = 20),
      axis.title = element_text(size = 24))

x2_bias_plot2 <- ggplot(x2_bias2, aes(y = fct_rev(label), x = bias)) +
  stat_halfeye() +
  geom_vline(xintercept = 0, alpha = 0.5, linetype = "dashed") +
  scale_y_discrete(name = "", labels = c("CPM", "QB20", "QB15", "QB10", "npCBGPS", "CBGPS", "OLS", "UW
  scale_x_continuous(name = "Bias", limits = c(-0.125, 0.125),
                     breaks = seq(-0.1, 0.1, 0.05), labels = seq(-0.1, 0.1, 0.05)) +
  theme +
  theme(axis.text = element_text(size = 20),
      axis.title = element_text(size = 24))

x3_bias_plot2 <- ggplot(x3_bias2, aes(y = fct_rev(label), x = bias)) +
  stat_halfeye() +
  geom_vline(xintercept = 0, alpha = 0.5, linetype = "dashed") +
  scale_y_discrete(name = "", labels = c("CPM", "QB20", "QB15", "QB10", "npCBGPS", "CBGPS", "OLS", "UW
  scale_x_continuous(name = "Bias", limits = c(-0.125, 0.125),
                     breaks = seq(-0.1, 0.1, 0.05), labels = seq(-0.1, 0.1, 0.05)) +
  theme +
  theme(axis.text = element_text(size = 20),
      axis.title = element_text(size = 24))

x4_bias_plot2 <- ggplot(x4_bias2, aes(y = fct_rev(label), x = bias)) +
  stat_halfeye() +
  geom_vline(xintercept = 0, alpha = 0.5, linetype = "dashed") +
  scale_y_discrete(name = "", labels = c("CPM", "npCBGPS", "CBGPS", "OLS", "UW")) +
  scale_x_continuous(name = "Bias", limits = c(-0.125, 0.125),
                     breaks = seq(-0.1, 0.1, 0.05), labels = seq(-0.1, 0.1, 0.05)) +
  theme +
  theme(axis.text = element_text(size = 20),
      axis.title = element_text(size = 24))

x5_bias_plot2 <- ggplot(x5_bias2, aes(y = fct_rev(label), x = bias)) +
  stat_halfeye() +
  geom_vline(xintercept = 0, alpha = 0.5, linetype = "dashed") +
  scale_y_discrete(name = "", labels = c("CPM", "npCBGPS", "CBGPS", "OLS", "UW")) +
  scale_x_continuous(name = "Bias", limits = c(-0.125, 0.125),
                     breaks = seq(-0.1, 0.1, 0.05), labels = seq(-0.1, 0.1, 0.05)) +
  theme +
  theme(axis.text = element_text(size = 20),
      axis.title = element_text(size = 24))
```

```r
  x6_bias_plot2 <- ggplot(x6_bias2, aes(y = fct_rev(label), x = bias)) +
    stat_halfeye() +
    geom_vline(xintercept = 0, alpha = 0.5, linetype = "dashed") +
    scale_y_discrete(name = "", labels = c("CPM", "npCBGPS", "CBGPS", "OLS", "UW")) +
    scale_x_continuous(name = "Bias", limits = c(-0.125, 0.125),
                       breaks = seq(-0.1, 0.1, 0.05), labels = seq(-0.1, 0.1, 0.05)) +
    theme +
    theme(axis.text = element_text(size = 20),
        axis.title = element_text(size = 24))

# combine plots
  ggarrange(x1_bias_plot2, x2_bias_plot2, x3_bias_plot2,
            x4_bias_plot2, x5_bias_plot2, x6_bias_plot2,
            labels = c(paste0("A", decile), paste0("B", decile), paste0("C", decile),
                       paste0("D", decile), paste0("E", decile), paste0("F", decile)),
            font.label = list(size = 28),
            nrow = 1)
}

# plot all deciles
aus_plots <- map(c(1:9), ~ aus_bias_plot(.x))
```

```r
# plots in chunks
ggarrange(aus_plots[[1]], aus_plots[[2]], aus_plots[[3]], ncol = 1)
#ggsave("./sim_png/supfig1.5_1.png")
ggarrange(aus_plots[[4]], aus_plots[[5]], aus_plots[[6]], ncol = 1)
#ggsave("./sim_png/supfig1.5_2.png")
ggarrange(aus_plots[[7]], aus_plots[[8]], aus_plots[[9]], ncol = 1)
#ggsave("./sim_png/supfig1.5_3.png")
```



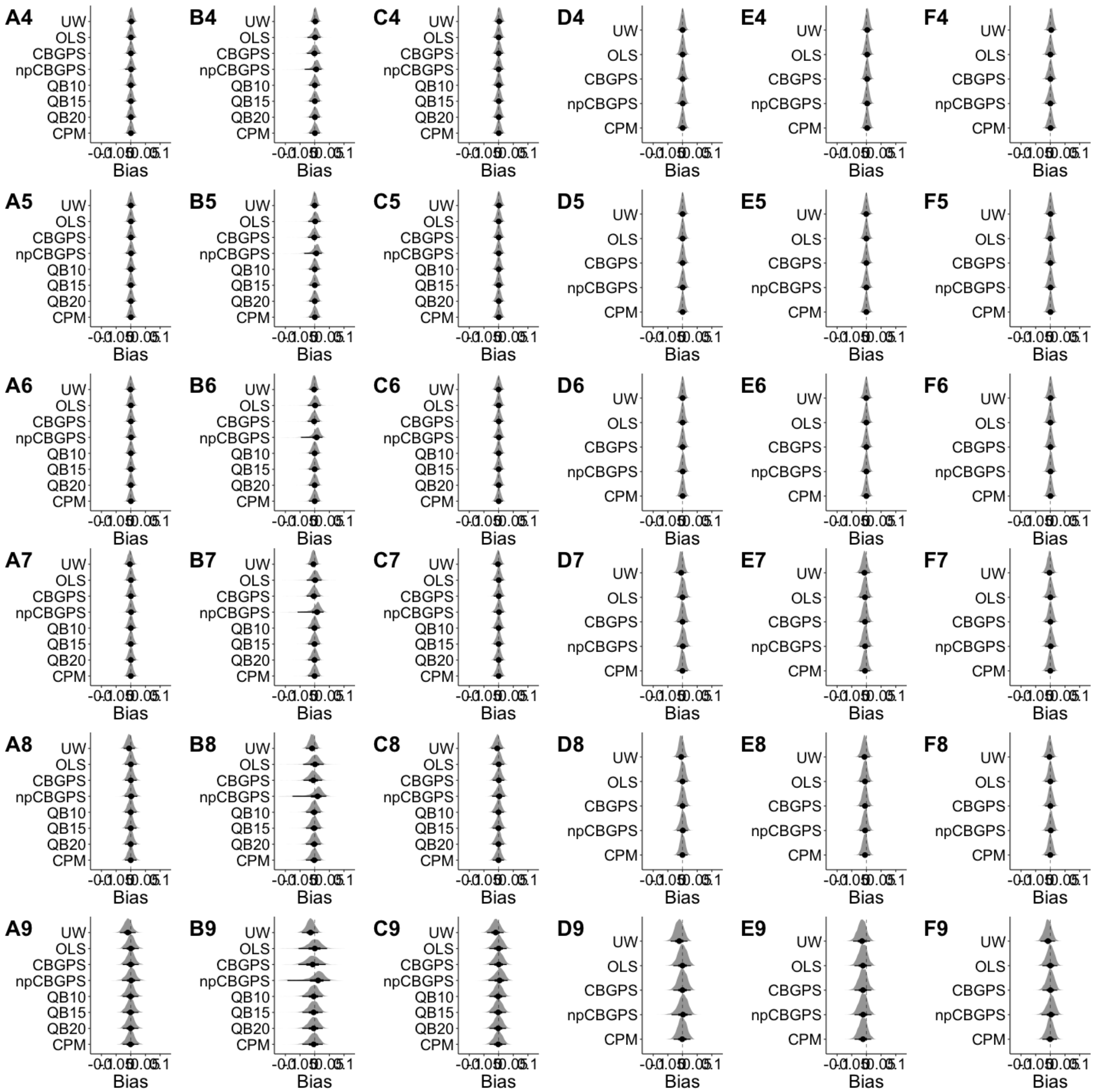


Figure legend: Column A) Homoscedastic Exposure, Conditionally Normal, Marginally Normal, Column B) Homoscedastic Exposure, Conditionally Normal, Marginally Non-Normal, Column C) Heteroscedastic Exposure, Conditionally Non-Normal, Marginally Non-Normal. The number next to each panel represents the decile, such that “A1” is the 1st decile of the Homoscedastic, Conditionally Normal, Marginally Normal Exposure.

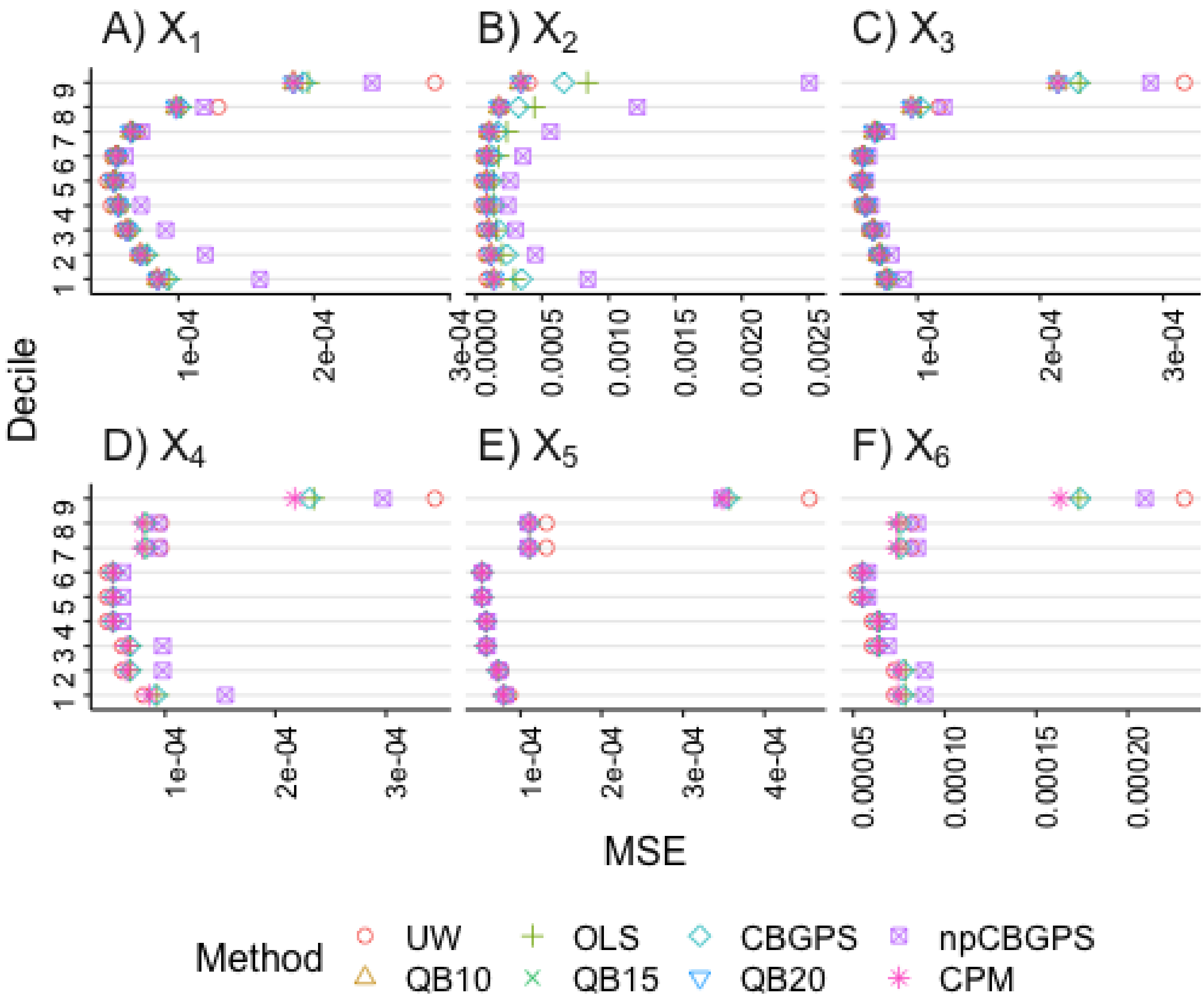
Web Figure 6 - Mean Squared Error at Deciles

```
# calculate mse for each scenario
austin_mse <- expand_grid(Decile = c(1:9),
                          Method = c("UW",
                                     "OLS",
                                     "CBGPS",
```

```r
                                     "npCBGPS",
                                     "QB10",
                                     "QB15",
                                     "QB20",
                                     "OLR"),
                          Exposure = c("x1",
                                       "x2",
                                       "x3",
                                       "x4",
                                       "x5",
                                       "x6"),
                          MSE = NA)

# now loop through and fill in cells
for(i in 1:nrow(austin_mse)){
  # create column name of bias tibble
  col_name <- paste0(austin_mse$Exposure[i], "_",
                     tolower(austin_mse$Method[i]), "_bias2_",
                     austin_mse$Decile[i])
  austin_mse$MSE[i] <- mean(bias[[col_name]]^2)
}

# Marginal Log Odds Ratio

mlor_mse <- expand_grid(Decile = c(0),
                        Method = c("UW",
                                   "OLS",
                                   "CBGPS",
                                   "npCBGPS",
                                   "QB10",
                                   "QB15",
                                   "QB20",
                                   "OLR"),
                        Exposure = c("x1",
                                     "x2",
                                     "x3",
                                     "x4",
                                     "x5",
                                     "x6"),
                        MSE = NA)

# now loop through and fill in cells
for(i in 1:nrow(mlor_mse)){
  # create column name of bias tibble
  col_name <- paste0(mlor_mse$Exposure[i], "_",
                     tolower(mlor_mse$Method[i]), "_bias")
  mlor_mse$MSE[i] <- mean(bias[[col_name]]^2)
}

# now combine
mse_plot <- bind_rows(austin_mse, mlor_mse) %>%
  mutate(Method = ifelse(Method == "OLR", "CPM", Method),
         Type = ifelse(Decile == 0, "MLOR", "Decile"))
```

```r
# now make plot

# first update levels
mse_plot <- mse_plot %>%
  mutate(Decile = factor(Decile),
         Method = factor(Method, levels = c("UW",
                                            "QB10",
                                     "OLS",
                                     "QB15",
                                     "CBGPS",
                                     "QB20",
                                     "npCBGPS",
                                     "CPM")),
         Exposure = factor(Exposure, levels = c("x1",
                                       "x2",
                                       "x3",
                                       "x4",
                                       "x5",
                                       "x6"))) %>%
  mutate(name = factor(Exposure,
                       labels = c(expression(paste("A) ", X[1])),
                                  expression(paste("B) ", X[2])),
                                  expression(paste("C) ", X[3])),
                                  expression(paste("D) ", X[4])),
                                  expression(paste("E) ", X[5])),
                                  expression(paste("F) ", X[6])))))

# fig 2
mse_plot %>% filter(Decile != 0) %>%
  ggplot(aes(x = MSE, y = Decile)) +
  # geom_vline(data = msm_mse,
  #            aes(xintercept = MSE, color = Method),
  #            linetype = "longdash", alpha = 0.9) +
  geom_point(aes(shape = Method, color = Method), size = 2.5) +
  facet_wrap(~name, ncol = 3, labeller = "label_parsed", scales = "free_x") +
  guides(color = list(guide_legend(nrow = 2))) +
  scale_shape_manual(values = 1:nlevels(mse_plot$Method)) +
  #scale_y_continuous(name = "Decile", breaks = 1:9) + # if you'd like to jitter things
  theme +
  theme(panel.grid.major.y = element_line(),
        axis.text = element_text(size = 12, angle = 90),
        axis.title = element_text(size = 16),
        legend.title = element_text(size = 16),
        legend.text = element_text(size = 14),
        strip.text = element_text(hjust = 0, size = 18),
        strip.background = element_blank())
```

```r
# save plot
#ggsave("./sim_png/supfig1.6.png", width = 10, height = 8)
```



Marginal Log Odds Ratio Approach

Figure 2 - Marginal Log Odds Ratio Approach Bias

```
# make df of x1:4 biases
x1_bias <- bias %>%
  select(starts_with("x1") & ends_with("bias")) %>%
  gather(label, bias) %>%
  mutate(label = factor(label,
                        levels = c("x1_uw_bias",
                                   "x1_ols_bias",
                                   "x1_cbgps_bias",
                                   "x1_npcbgps_bias",
                                   "x1_qb10_bias",
                                   "x1_qb15_bias",
                                   "x1_qb20_bias",
                                   "x1_olr_bias")),
         facet = str_sub(label, 1, 2),
         lab = str_sub(label, 4))
```

```r
x2_bias <- bias %>%
  select(starts_with("x2") & ends_with("bias")) %>%
  gather(label, bias) %>%
  mutate(label = factor(label,
                        levels = c("x2_uw_bias",
                                   "x2_ols_bias",
                                   "x2_cbgps_bias",
                                   "x2_npcbgps_bias",
                                   "x2_qb10_bias",
                                   "x2_qb15_bias",
                                   "x2_qb20_bias",
                                   "x2_olr_bias")),
         facet = str_sub(label, 1, 2),
         lab = str_sub(label, 4))

x3_bias <- bias %>%
  select(starts_with("x3") & ends_with("bias")) %>%
  gather(label, bias) %>%
  mutate(label = factor(label,
                        levels = c("x3_uw_bias",
                                   "x3_ols_bias",
                                   "x3_cbgps_bias",
                                   "x3_npcbgps_bias",
                                   "x3_qb10_bias",
                                   "x3_qb15_bias",
                                   "x3_qb20_bias",
                                   "x3_olr_bias")),
         facet = str_sub(label, 1, 2),
         lab = str_sub(label, 4))

x4_bias <- bias %>%
  select(starts_with("x4") & ends_with("bias")) %>%
  gather(label, bias) %>%
  mutate(label = factor(label,
                        levels = c("x4_uw_bias",
                                   "x4_ols_bias",
                                   "x4_cbgps_bias",
                                   "x4_npcbgps_bias",
                                   "x4_olr_bias")),
         facet = str_sub(label, 1, 2),
         lab = str_sub(label, 4))

x5_bias <- bias %>%
  select(starts_with("x5") & ends_with("bias")) %>%
  gather(label, bias) %>%
  mutate(label = factor(label,
                        levels = c("x5_uw_bias",
                                   "x5_ols_bias",
                                   "x5_cbgps_bias",
                                   "x5_npcbgps_bias",
                                   "x5_olr_bias")),
         facet = str_sub(label, 1, 2),
         lab = str_sub(label, 4))
```

```r
x6_bias <- bias %>%
  select(starts_with("x6") & ends_with("bias")) %>%
  gather(label, bias) %>%
  mutate(label = factor(label,
                        levels = c("x6_uw_bias",
                                   "x6_ols_bias",
                                   "x6_cbgps_bias",
                                   "x6_npcbgps_bias",
                                   "x6_olr_bias")),
         facet = str_sub(label, 1, 2),
         lab = str_sub(label, 4))

# combine into one dataset so can make facet plot
mse_bias_plot <- bind_rows(x1_bias, x2_bias, x3_bias, x4_bias, x5_bias, x6_bias) %>%
  mutate(facet = factor(facet, levels = c("x1", "x2", "x3", "x4", "x5", "x6")),
         lab = factor(lab,levels = c("uw_bias",
                                   "ols_bias",
                                   "cbgps_bias",
                                   "npcbgps_bias",
                                   "qb10_bias",
                                   "qb15_bias",
                                   "qb20_bias",
                                   "olr_bias"))) %>%
  mutate(name = factor(facet,
                       labels = c(expression(paste("A) ", X[1])),
                                  expression(paste("B) ", X[2])),
                                  expression(paste("C) ", X[3])),
                                  expression(paste("D) ", X[4])),
                                  expression(paste("E) ", X[5])),
                                  expression(paste("F) ", X[6])))))

# now plot with both austin and molr mse...
fig2_func <- function(exp_num, letter) {

  if(exp_num < 4) {
    mse_bias_plot %>% filter(facet == paste0("x", exp_num), bias < 0.25, bias > -0.25) %>%
      ggplot(aes(y = fct_rev(lab), x = bias)) +
      stat_halfeye() +
      geom_vline(xintercept = 0, alpha = 0.5, linetype = "dashed") +
      scale_y_discrete(name = "", labels = c("CPM", "QB20", "QB15", "QB10", "npCBGPS", "CBGPS", "OLS",
      scale_x_continuous(name = "Bias",
                         breaks = seq(-0.2, 0.2, 0.1), labels = c("-0.2", "-0.1", "0.0", "0.1", "0.2")) +
      annotate(geom = "text", x = -0.3, y = 9.3, label = paste0(letter, ")"), size = 8 / .pt) +
      annotate(geom = "text", x = 0.325, y = 9, label = "underline('MSE')", size = 8 / .pt, parse = TRUI
      annotate(geom = "text", x = 0.325, y = 8.5, label = mlor_mse %>%
                 filter(Exposure == paste0("x", exp_num) & Method == "UW") %>%
                 pull(MSE) %>% round(4) %>% format(nsmall = 4), size = 8 / .pt) +
      annotate(geom = "text", x = 0.325, y = 7.5, label = mlor_mse %>%
                 filter(Exposure == paste0("x", exp_num) & Method == "OLS") %>%
                 pull(MSE) %>% round(4) %>% format(nsmall = 4), size = 8 / .pt) +
      annotate(geom = "text", x = 0.325, y = 6.5, label = mlor_mse %>%
                 filter(Exposure == paste0("x", exp_num) & Method == "CBGPS") %>%
                 pull(MSE) %>% round(4) %>% format(nsmall = 4), size = 8 / .pt) +
```

```
    annotate(geom = "text", x = 0.325, y = 5.5, label = mlor_mse %>%
               filter(Exposure == paste0("x", exp_num) & Method == "npCBGPS") %>%
               pull(MSE) %>% round(4) %>% format(nsmall = 4), size = 8 / .pt) +
    annotate(geom = "text", x = 0.325, y = 4.5, label = mlor_mse %>%
               filter(Exposure == paste0("x", exp_num) & Method == "QB10") %>%
               pull(MSE) %>% round(4) %>% format(nsmall = 4), size = 8 / .pt) +
    annotate(geom = "text", x = 0.325, y = 3.5, label = mlor_mse %>%
               filter(Exposure == paste0("x", exp_num) & Method == "QB15") %>%
               pull(MSE) %>% round(4) %>% format(nsmall = 4), size = 8 / .pt) +
    annotate(geom = "text", x = 0.325, y = 2.5, label = mlor_mse %>%
               filter(Exposure == paste0("x", exp_num) & Method == "QB20") %>%
               pull(MSE) %>% round(4) %>% format(nsmall = 4), size = 8 / .pt) +
    annotate(geom = "text", x = 0.325, y = 1.5, label = mlor_mse %>%
               filter(Exposure == paste0("x", exp_num) & Method == "OLR") %>%
               pull(MSE) %>% round(4) %>% format(nsmall = 4), size = 8 / .pt) +
    ggtitle("") +
    coord_cartesian(clip = "off", ylim = c(1, 8.5), xlim = c(-0.25, 0.25)) +
    theme +
    theme(panel.grid.major.y = element_line(),
          title = element_text(size = 8),
          axis.title = element_text(size = 8),
          axis.text = element_text(size = 8),
          plot.margin = unit(c(3, 22, 3, 3), "pt"),
          legend.position = "none")
} else {
  mse_bias_plot %>% filter(facet == paste0("x", exp_num), bias < 0.25, bias > -0.25) %>%
    ggplot(aes(y = fct_rev(lab), x = bias)) +
    stat_halfeye() +
    geom_vline(xintercept = 0, alpha = 0.5, linetype = "dashed") +
    scale_y_discrete(name = "", labels = c("CPM", "npCBGPS", "CBGPS", "OLS", "UW")) +
    scale_x_continuous(name = "Bias",
                       breaks = seq(-0.2, 0.2, 0.1), labels = c("-0.2", "-0.1", "0.0", "0.1", "0.2")) +
    annotate(geom = "text", x = -0.3, y = 6.3, label = paste0(letter, ")"), size = 8 / .pt) +
    annotate(geom = "text", x = 0.325, y = 6, label = "underline('MSE')", size = 8 / .pt, parse = TRUE
    annotate(geom = "text", x = 0.325, y = 5.5, label = mlor_mse %>%
                filter(Exposure == paste0("x", exp_num) & Method == "UW") %>%
               pull(MSE) %>% round(4) %>% format(nsmall = 4), size = 8 / .pt) +
    annotate(geom = "text", x = 0.325, y = 4.5, label = mlor_mse %>%
               filter(Exposure == paste0("x", exp_num) & Method == "OLS") %>%
               pull(MSE) %>% round(4) %>% format(nsmall = 4), size = 8 / .pt) +
    annotate(geom = "text", x = 0.325, y = 3.5, label = mlor_mse %>%
               filter(Exposure == paste0("x", exp_num) & Method == "CBGPS") %>%
               pull(MSE) %>% round(4) %>% format(nsmall = 4), size = 8 / .pt) +
    annotate(geom = "text", x = 0.325, y = 2.5, label = mlor_mse %>%
               filter(Exposure == paste0("x", exp_num) & Method == "npCBGPS") %>%
               pull(MSE) %>% round(4) %>% format(nsmall = 4), size = 8 / .pt) +
    annotate(geom = "text", x = 0.325, y = 1.5, label = mlor_mse %>%
               filter(Exposure == paste0("x", exp_num) & Method == "OLR") %>%
               pull(MSE) %>% round(4) %>% format(nsmall = 4), size = 8 / .pt) +
    coord_cartesian(clip = "off", ylim = c(1, 5.5), xlim = c(-0.25, 0.25)) +
    theme +
    theme(panel.grid.major.y = element_line(),
          axis.title = element_text(size = 8),
```

```
            axis.text = element_text(size = 8),
            plot.margin = unit(c(3, 22, 3, 3), "pt"),
            legend.position = "none")
  }
}

fig2_fin <- ggarrange(fig2_func(1, "A"),
          fig2_func(2, "B"),
          fig2_func(3, "C"),
          fig2_func(4, "D"),
          fig2_func(5, "E"),
          fig2_func(6, "F"),
          ncol = 3,
          nrow = 2,
          heights = c(8, 5),
          align= "hv")

annotate_figure(fig2_fin,
                left = text_grob("Stabilized Inverse Probability Weighting Approach", rot = 90, size = 9

# save plot
ggsave("fin_figs/fig2.pdf", width = 7, height = 7)
# embed the font
embed_fonts("fin_figs/fig2.pdf")
```

Figure 2 Panels

```
# Panel A
fig2_func(1, "A")
ggsave("fin_figs/fig2a.pdf", width = 2.33, height = 4.67)
embed_fonts("fin_figs/fig2a.pdf")

# Panel B
fig2_func(2, "B")
ggsave("fin_figs/fig2b.pdf", width = 2.33, height = 4.67)
embed_fonts("fin_figs/fig2b.pdf")

# Panel C
fig2_func(3, "C")
ggsave("fin_figs/fig2c.pdf", width = 2.33, height = 4.67)
embed_fonts("fin_figs/fig2c.pdf")

# Panel D
fig2_func(4, "D")
ggsave("fin_figs/fig2d.pdf", width = 2.33, height = 2.92)
embed_fonts("fin_figs/fig2d.pdf")

# Panel E
fig2_func(5, "E")
ggsave("fin_figs/fig2e.pdf", width = 2.33, height = 2.92)
embed_fonts("fin_figs/fig2e.pdf")
```

```r
# Panel F
fig2_func(6, "F")
ggsave("fin_figs/fig2f.pdf", width = 2.33, height = 2.92)
embed_fonts("fin_figs/fig2f.pdf")
```

Mean Squared Error

Table 3 - Marginal Log Odds Ratio Approach Standard Error Ratio and Coverage

```r
# now make table of mean squared error, which is the mean of the squared biases (or errors)
tab3 <- tibble(Method = c("Unweighted",
                            "Standard Error Ratio",
                            "Coverage",
                          "Ordinary least squares",
                            "Standard Error Ratio",
                            "Coverage",
                          "Covariate balancing generalized propensity score",
                            "Standard Error Ratio",
                            "Coverage",
                          "Non-parametric covariate balancing generalized propensity score",
                            "Standard Error Ratio",
                            "Coverage",
                          "Quantile binning categories",
                          "10",
                            "Standard Error Ratio",
                            "Coverage",
                          "15",
                            "Standard Error Ratio",
                            "Coverage",
                          "20",
                            "Standard Error Ratio",
                            "Coverage",
                          "Ordinal logistic regression",
                            "Standard Error Ratio",
                            "Coverage"),
               `X1` = c(NA,
                        mean(bias$x1_uw_se) / sd(true_x1 - bias$x1_uw_bias),
                        mean(bias$x1_uw_cov),
                        NA,
                        mean(bias$x1_ols_se) / sd(true_x1 - bias$x1_ols_bias),
                        mean(bias$x1_ols_cov),
                        NA,
                        mean(bias$x1_cbgps_se) / sd(true_x1 - bias$x1_cbgps_bias),
                        mean(bias$x1_cbgps_cov),
                        NA,
                        mean(bias$x1_npcbgps_se) / sd(true_x1 - bias$x1_npcbgps_bias),
                        mean(bias$x1_npcbgps_cov),
                        NA,
                        NA,
                        mean(bias$x1_qb10_se) / sd(true_x1 - bias$x1_qb10_bias),
                        mean(bias$x1_qb10_cov),
                        NA,
```

```
              mean(bias$x1_qb15_se) / sd(true_x1 - bias$x1_qb15_bias),
              mean(bias$x1_qb15_cov),
              NA,
              mean(bias$x1_qb20_se) / sd(true_x1 - bias$x1_qb20_bias),
              mean(bias$x1_qb20_cov),
              NA,
              mean(bias$x1_olr_se) / sd(true_x1 - bias$x1_olr_bias),
              mean(bias$x1_olr_cov)),
     `X4` = c(NA,
              mean(bias$x4_uw_se) / sd(true_x4 - bias$x4_uw_bias),
              mean(bias$x4_uw_cov),
              NA,
              mean(bias$x4_ols_se) / sd(true_x4 - bias$x4_ols_bias),
              mean(bias$x4_ols_cov),
              NA,
              mean(bias$x4_cbgps_se) / sd(true_x4 - bias$x4_cbgps_bias),
              mean(bias$x4_cbgps_cov),
              NA,
              mean(bias$x4_npcbgps_se) / sd(true_x4 - bias$x4_npcbgps_bias),
              mean(bias$x4_npcbgps_cov),
              NA,
              NA, NA, NA,
              NA, NA, NA,
              NA, NA, NA,
              NA,
              mean(bias$x4_olr_se) / sd(true_x4 - bias$x4_olr_bias),
              mean(bias$x4_olr_cov)),
     `X2` = c(NA,
              mean(bias$x2_uw_se) / sd(true_x2 - bias$x2_uw_bias),
              mean(bias$x2_uw_cov),
              NA,
              mean(bias$x2_ols_se) / sd(true_x2 - bias$x2_ols_bias),
              mean(bias$x2_ols_cov),
              NA,
              mean(bias$x2_cbgps_se) / sd(true_x2 - bias$x2_cbgps_bias),
              mean(bias$x2_cbgps_cov),
              NA,
              mean(bias$x2_npcbgps_se) / sd(true_x2 - bias$x2_npcbgps_bias),
              mean(bias$x2_npcbgps_cov),
              NA,
              NA,
              mean(bias$x2_qb10_se) / sd(true_x2 - bias$x2_qb10_bias),
              mean(bias$x2_qb10_cov),
              NA,
              mean(bias$x2_qb15_se) / sd(true_x2 - bias$x2_qb15_bias),
              mean(bias$x2_qb15_cov),
              NA,
              mean(bias$x2_qb20_se) / sd(true_x2 - bias$x2_qb20_bias),
              mean(bias$x2_qb20_cov),
              NA,
              mean(bias$x2_olr_se) / sd(true_x2 - bias$x2_olr_bias),
              mean(bias$x2_olr_cov)),
     `X5` = c(NA,
```

```
                mean(bias$x5_uw_se) / sd(true_x5 - bias$x5_uw_bias),
                mean(bias$x5_uw_cov),
                NA,
                mean(bias$x5_ols_se) / sd(true_x5 - bias$x5_ols_bias),
                mean(bias$x5_ols_cov),
                NA,
                mean(bias$x5_cbgps_se) / sd(true_x5 - bias$x5_cbgps_bias),
                mean(bias$x5_cbgps_cov),
                NA,
                mean(bias$x5_npcbgps_se) / sd(true_x5 - bias$x5_npcbgps_bias),
                mean(bias$x5_npcbgps_cov),
                NA,
                NA, NA, NA,
                NA, NA, NA,
                NA, NA, NA,
                NA,
                mean(bias$x5_olr_se) / sd(true_x5 - bias$x5_olr_bias),
                mean(bias$x5_olr_cov)),
         `X3` = c(NA,
                mean(bias$x3_uw_se) / sd(true_x3 - bias$x3_uw_bias),
                mean(bias$x3_uw_cov),
                NA,
                mean(bias$x3_ols_se) / sd(true_x3 - bias$x3_ols_bias),
                mean(bias$x3_ols_cov),
                NA,
                mean(bias$x3_cbgps_se) / sd(true_x3 - bias$x3_cbgps_bias),
                mean(bias$x3_cbgps_cov),
                NA,
                mean(bias$x3_npcbgps_se) / sd(true_x3 - bias$x3_npcbgps_bias),
                mean(bias$x3_npcbgps_cov),
                NA,
                NA,
                mean(bias$x3_qb10_se) / sd(true_x3 - bias$x3_qb10_bias),
                mean(bias$x3_qb10_cov),
                NA,
                mean(bias$x3_qb15_se) / sd(true_x3 - bias$x3_qb15_bias),
                mean(bias$x3_qb15_cov),
                NA,
                mean(bias$x3_qb20_se) / sd(true_x3 - bias$x3_qb20_bias),
                mean(bias$x3_qb20_cov),
                NA,
                mean(bias$x3_olr_se) / sd(true_x3 - bias$x3_olr_bias),
                mean(bias$x3_olr_cov)),
         `X6` = c(NA,
                mean(bias$x6_uw_se) / sd(true_x6 - bias$x6_uw_bias),
                mean(bias$x6_uw_cov),
                NA,
                mean(bias$x6_ols_se) / sd(true_x6 - bias$x6_ols_bias),
                mean(bias$x6_ols_cov),
                NA,
                mean(bias$x6_cbgps_se) / sd(true_x6 - bias$x6_cbgps_bias),
                mean(bias$x6_cbgps_cov),
                NA,
```

```
                         mean(bias$x6_npcbgps_se) / sd(true_x6 - bias$x6_npcbgps_bias),
                         mean(bias$x6_npcbgps_cov),
                         NA,
                         NA, NA, NA,
                         NA, NA, NA,
                         NA, NA, NA,
                         NA,
                         mean(bias$x6_olr_se) / sd(true_x6 - bias$x6_olr_bias),
                         mean(bias$x6_olr_cov))
                )

# make table
kable(tab3, digits = 3) %>%
  kable_classic(html_font = "Arial", full_width = FALSE) %>%
  add_header_above(c("Marginally", "Normal" = 2, "Non-Normal" = 2,
                     "Non-Normal" = 2), bold = TRUE) %>%
  add_header_above(c("Conditionally", "Normal" = 2, "Normal" = 2,
                     "Non-Normal" = 2), bold = TRUE) %>%
  add_indent(c(2:3, 5:6, 8:9, 11:12, 15:16, 18:19, 21:22, 24:25)) %>%
  add_indent(c(2:3, 5:6, 8:9, 11:12, 13:22, 24:25))
```

Web Table 4 - Marginal Log Odds Ratio Approach Bias

```
# now make table of biases
tab4 <- tibble(Method = c("Unweighted",
                          "Ordinary least squares",
                          "Covariate balancing generalized propensity score",
                          "Non-parametric covariate balancing generalized propensity score",
                          "Quantile binning categories",
                          "10",
                          "15",
                          "20",
                          "Ordinal logistic regression"),
               `Median Bias (IQR)` = c(paste0(round(median(bias$x1_uw_bias), 4), " (",
                                              round(quantile(bias$x1_uw_bias, 0.25), 3), ", ",
                                              round(quantile(bias$x1_uw_bias, 0.75), 3), ")"),
                                        paste0(round(median(bias$x1_ols_bias), 4), " (",
                                              round(quantile(bias$x1_ols_bias, 0.25), 3), ", ",
                                              round(quantile(bias$x1_ols_bias, 0.75), 3), ")"),
                                      paste0(round(median(bias$x1_cbgps_bias), 4), " (",
                                              round(quantile(bias$x1_cbgps_bias, 0.25), 3), ", ",
                                              round(quantile(bias$x1_cbgps_bias, 0.75), 3), ")"),
                                      paste0(round(median(bias$x1_npcbgps_bias), 4), " (",
                                              round(quantile(bias$x1_npcbgps_bias, 0.25), 3), ", ",
                                              round(quantile(bias$x1_npcbgps_bias, 0.75), 3), ")"),
                                      NA,
                                      paste0(round(median(bias$x1_qb10_bias), 4), " (",
                                              round(quantile(bias$x1_qb10_bias, 0.25), 3), ", ",
                                              round(quantile(bias$x1_qb10_bias, 0.75), 3), ")"),
                                      paste0(round(median(bias$x1_qb15_bias), 4), " (",
                                              round(quantile(bias$x1_qb15_bias, 0.25), 3), ", ",
                                              round(quantile(bias$x1_qb15_bias, 0.75), 3), ")"),
```

```
                                paste0(round(median(bias$x1_qb20_bias), 4), " (",
                                      round(quantile(bias$x1_qb20_bias, 0.25), 3), ", ",
                                      round(quantile(bias$x1_qb20_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x1_olr_bias), 4), " (",
                                      round(quantile(bias$x1_olr_bias, 0.25), 3), ", ",
                                      round(quantile(bias$x1_olr_bias, 0.75), 3), ")")),
             `Median Bias (IQR)   ` = c(paste0(round(median(bias$x4_uw_bias), 4), " (",
                                      round(quantile(bias$x4_uw_bias, 0.25), 3), ", ",
                                      round(quantile(bias$x4_uw_bias, 0.75), 3), ")"),
                                  paste0(round(median(bias$x4_ols_bias), 4), " (",
                                      round(quantile(bias$x4_ols_bias, 0.25), 3), ", ",
                                      round(quantile(bias$x4_ols_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x4_cbgps_bias), 4), " (",
                                      round(quantile(bias$x4_cbgps_bias, 0.25), 3), ", ",
                                      round(quantile(bias$x4_cbgps_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x4_npcbgps_bias), 4), " (",
                                      round(quantile(bias$x4_npcbgps_bias, 0.25), 3), ", ",
                                      round(quantile(bias$x4_npcbgps_bias, 0.75), 3), ")"),
                                NA,
                                NA,
                                NA,
                                NA,
                                paste0(round(median(bias$x4_olr_bias), 4), " (",
                                      round(quantile(bias$x4_olr_bias, 0.25), 3), ", ",
                                      round(quantile(bias$x4_olr_bias, 0.75), 3), ")")),
             `Median Bias (IQR) ` = c(paste0(round(median(bias$x2_uw_bias), 4), " (",
                                      round(quantile(bias$x2_uw_bias, 0.25), 3), ", ",
                                      round(quantile(bias$x2_uw_bias, 0.75), 3), ")"),
                                   paste0(round(median(bias$x2_ols_bias), 4), " (",
                                      round(quantile(bias$x2_ols_bias, 0.25), 3), ", ",
                                      round(quantile(bias$x2_ols_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x2_cbgps_bias), 4), " (",
                                      round(quantile(bias$x2_cbgps_bias, 0.25), 3), ", ",
                                      round(quantile(bias$x2_cbgps_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x2_npcbgps_bias), 4), " (",
                                      round(quantile(bias$x2_npcbgps_bias, 0.25), 3), ", ",
                                      round(quantile(bias$x2_npcbgps_bias, 0.75), 3), ")"),
                                NA,
                                paste0(round(median(bias$x2_qb10_bias), 4), " (",
                                      round(quantile(bias$x2_qb10_bias, 0.25), 3), ", ",
                                      round(quantile(bias$x2_qb10_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x2_qb15_bias), 4), " (",
                                      round(quantile(bias$x2_qb15_bias, 0.25), 3), ", ",
                                      round(quantile(bias$x2_qb15_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x2_qb20_bias), 4), " (",
                                      round(quantile(bias$x2_qb20_bias, 0.25), 3), ", ",
                                      round(quantile(bias$x2_qb20_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x2_olr_bias), 4), " (",
                                      round(quantile(bias$x2_olr_bias, 0.25), 3), ", ",
                                      round(quantile(bias$x2_olr_bias, 0.75), 3), ")")),
             `Median Bias (IQR)    ` = c(paste0(round(median(bias$x5_uw_bias), 4), " (",
                                      round(quantile(bias$x5_uw_bias, 0.25), 3), ", ",
                                      round(quantile(bias$x5_uw_bias, 0.75), 3), ")"),
```

```
                                  paste0(round(median(bias$x5_ols_bias), 4), " (",
                                       round(quantile(bias$x5_ols_bias, 0.25), 3), ", ",
                                       round(quantile(bias$x5_ols_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x5_cbgps_bias), 4), " (",
                                       round(quantile(bias$x5_cbgps_bias, 0.25), 3), ", ",
                                       round(quantile(bias$x5_cbgps_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x5_npcbgps_bias), 4), " (",
                                       round(quantile(bias$x5_npcbgps_bias, 0.25), 3), ", ",
                                       round(quantile(bias$x5_npcbgps_bias, 0.75), 3), ")"),
                                NA,
                                NA,
                                NA,
                                NA,
                                paste0(round(median(bias$x5_olr_bias), 4), " (",
                                       round(quantile(bias$x5_olr_bias, 0.25), 3), ", ",
                                       round(quantile(bias$x5_olr_bias, 0.75), 3), ")")),
              `Median Bias (IQR)  ` = c(paste0(round(median(bias$x3_uw_bias), 4), " (",
                                       round(quantile(bias$x3_uw_bias, 0.25), 3), ", ",
                                       round(quantile(bias$x3_uw_bias, 0.75), 3), ")"),
                                    paste0(round(median(bias$x3_ols_bias), 4), " (",
                                       round(quantile(bias$x3_ols_bias, 0.25), 3), ", ",
                                       round(quantile(bias$x3_ols_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x3_cbgps_bias), 4), " (",
                                       round(quantile(bias$x3_cbgps_bias, 0.25), 3), ", ",
                                       round(quantile(bias$x3_cbgps_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x3_npcbgps_bias), 4), " (",
                                       round(quantile(bias$x3_npcbgps_bias, 0.25), 3), ", ",
                                       round(quantile(bias$x3_npcbgps_bias, 0.75), 3), ")"),
                                NA,
                                paste0(round(median(bias$x3_qb10_bias), 4), " (",
                                       round(quantile(bias$x3_qb10_bias, 0.25), 3), ", ",
                                       round(quantile(bias$x3_qb10_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x3_qb15_bias), 4), " (",
                                       round(quantile(bias$x3_qb15_bias, 0.25), 3), ", ",
                                       round(quantile(bias$x3_qb15_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x3_qb20_bias), 4), " (",
                                       round(quantile(bias$x3_qb20_bias, 0.25), 3), ", ",
                                       round(quantile(bias$x3_qb20_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x3_olr_bias), 4), " (",
                                       round(quantile(bias$x3_olr_bias, 0.25), 3), ", ",
                                       round(quantile(bias$x3_olr_bias, 0.75), 3), ")")),
              `Median Bias (IQR)     ` = c(paste0(round(median(bias$x6_uw_bias), 4), " (",
                                       round(quantile(bias$x6_uw_bias, 0.25), 3), ", ",
                                       round(quantile(bias$x6_uw_bias, 0.75), 3), ")"),
                                  paste0(round(median(bias$x6_ols_bias), 4), " (",
                                       round(quantile(bias$x6_ols_bias, 0.25), 3), ", ",
                                       round(quantile(bias$x6_ols_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x6_cbgps_bias), 4), " (",
                                       round(quantile(bias$x6_cbgps_bias, 0.25), 3), ", ",
                                       round(quantile(bias$x6_cbgps_bias, 0.75), 3), ")"),
                                paste0(round(median(bias$x6_npcbgps_bias), 4), " (",
                                       round(quantile(bias$x6_npcbgps_bias, 0.25), 3), ", ",
                                       round(quantile(bias$x6_npcbgps_bias, 0.75), 3), ")"),
```

```r
                                          NA,
                                          NA,
                                          NA,
                                          NA,
                                          paste0(round(median(bias$x6_olr_bias), 4), " (",
                                                 round(quantile(bias$x6_olr_bias, 0.25), 3), ", ",
                                                 round(quantile(bias$x6_olr_bias, 0.75), 3), ")"))
                )

# make table
kable(tab4) %>%
  kable_classic(html_font = "Arial", full_width = TRUE) %>%
  add_header_above(c("", "X1" = 1, "X4" = 1, "X2" = 1,
                     "X5" = 1, "X3" = 1, "X6" = 1), bold = TRUE) %>%
  add_header_above(c("Marginally", "Normal" = 2, "Non-Normal" = 2,
                     "Non-Normal" = 2), bold = TRUE) %>%
  add_header_above(c("Conditionally", "Normal" = 2, "Normal" = 2,
                     "Non-Normal" = 2), bold = TRUE) %>%
  add_indent(c(6:8))
```

Conditionally	**Normal**		**Normal**		**Non-Normal**	
Marginally	**Normal**		**Non-Normal**		**Non-Normal**	
	X1	**X4**	**X2**	**X5**	**X3**	**X6**
Method	Median Bias (IQR)	Median Bias (IQR)	Median Bias (IQR)	Median Bias (IQR)	Median Bias (IQR)	Median Bias (IQR)
Unweighted	-0.0613 (-0.107, -0.014)	-0.055 (-0.103, -0.01)	-0.0647 (-0.104, -0.029)	-0.0633 (-0.102, -0.026)	-0.0415 (-0.076, -0.009)	-0.0403 (-0.076, -0.006)
Ordinary least squares	-0.0024 (-0.055, 0.048)	-5e-04 (-0.054, 0.05)	-0.0118 (-0.077, 0.056)	-0.0507 (-0.089, -0.013)	-2e-04 (-0.04, 0.038)	-3e-04 (-0.039, 0.039)
Covariate balancing generalized propensity score	-0.0026 (-0.055, 0.049)	-1e-04 (-0.054, 0.05)	-0.0277 (-0.097, 0.054)	-0.0506 (-0.088, -0.013)	-8e-04 (-0.039, 0.038)	-4e-04 (-0.039, 0.038)
Non-parametric covariate balancing generalized propensity score	-8e-04 (-0.058, 0.056)	0.0023 (-0.054, 0.059)	-5e-04 (-0.071, 0.064)	-0.0496 (-0.087, -0.01)	0.01 (-0.034, 0.051)	0.0086 (-0.032, 0.049)
Quantile binning categories						
10	-0.009 (-0.059, 0.042)		-0.0207 (-0.074, 0.037)		-0.0084 (-0.046, 0.028)	
15	-0.0082 (-0.059, 0.043)		-0.0214 (-0.074, 0.036)		-0.0082 (-0.046, 0.029)	
20	-0.0077 (-0.058, 0.043)		-0.0209 (-0.075, 0.036)		-0.008 (-0.045, 0.029)	
Ordinal logistic regression	-0.0073 (-0.058, 0.044)	-0.0044 (-0.055, 0.045)	-0.0196 (-0.075, 0.035)	-0.049 (-0.087, -0.012)	-0.0079 (-0.045, 0.029)	-0.0072 (-0.044, 0.032)

Session Info

```
sessionInfo()
```

```
R version 4.1.0 (2021-05-18)
Platform: aarch64-apple-darwin20 (64-bit)
Running under: macOS 12.6

Matrix products: default
BLAS:   /Library/Frameworks/R.framework/Versions/4.1-arm64/Resources/lib/libRblas.dylib
LAPACK: /Library/Frameworks/R.framework/Versions/4.1-arm64/Resources/lib/libRlapack.dylib

Random number generation:
 RNG:     L'Ecuyer-CMRG
 Normal:  Inversion
```

```
 Sample:  Rejection

locale:
[1] en_US.UTF-8/en_US.UTF-8/en_US.UTF-8/C/en_US.UTF-8/en_US.UTF-8

attached base packages:
[1] grid      parallel  stats     graphics  grDevices utils     datasets
[8] methods   base

other attached packages:
 [1] survey_4.1-1      ggdist_3.0.0      extrafont_0.17    doParallel_1.0.16
 [5] iterators_1.0.14  foreach_1.5.2     furrr_0.2.3       future_1.23.0
 [9] ggpubr_0.4.0      kableExtra_1.3.4  lme4_1.1-27.1     Matrix_1.3-4
[13] cobalt_4.3.1      MatchThem_1.0.1   WeightIt_0.12.0   mice_3.13.0
[17] rms_6.2-0         SparseM_1.81      Hmisc_4.6-0       Formula_1.2-4
[21] survival_3.2-13   lattice_0.20-45   forcats_0.5.1     stringr_1.4.0
[25] dplyr_1.0.8       purrr_0.3.4       readr_2.0.2       tidyr_1.2.0
[29] tibble_3.1.6      ggplot2_3.3.5     tidyverse_1.3.1

loaded via a namespace (and not attached):
  [1] readxl_1.3.1        backports_1.3.0      systemfonts_1.0.3
  [4] plyr_1.8.6          splines_4.1.0        listenv_0.8.0
  [7] TH.data_1.1-0       digest_0.6.29        htmltools_0.5.2
 [10] magick_2.7.3        fansi_1.0.2          magrittr_2.0.2
 [13] checkmate_2.0.0     cluster_2.1.2        tzdb_0.2.0
 [16] recipes_0.1.17      globals_0.14.0       modelr_0.1.8
 [19] gower_0.2.2         matrixStats_0.61.0   extrafontdb_1.0
 [22] sandwich_3.0-1      svglite_2.0.0        jpeg_0.1-9
 [25] colorspace_2.0-3    rvest_1.0.2          mitools_2.4
 [28] haven_2.4.3         xfun_0.30            crayon_1.5.0
 [31] jsonlite_1.8.0      zoo_1.8-9            glue_1.6.2
 [34] gtable_0.3.0        ipred_0.9-12         webshot_0.5.2
 [37] MatrixModels_0.5-0  distributional_0.2.2 car_3.0-12
 [40] Rttf2pt1_1.3.9      future.apply_1.8.1   abind_1.4-5
 [43] scales_1.1.1        mvtnorm_1.1-3        DBI_1.1.1
 [46] rstatix_0.7.0       Rcpp_1.0.8.3         viridisLite_0.4.0
 [49] htmlTable_2.3.0     foreign_0.8-81       stats4_4.1.0
 [52] lava_1.6.10         prodlim_2019.11.13   htmlwidgets_1.5.4
 [55] httr_1.4.2          MatchIt_4.3.0        RColorBrewer_1.1-2
 [58] ellipsis_0.3.2      farver_2.1.0         pkgconfig_2.0.3
 [61] nnet_7.3-16         dbplyr_2.1.1         utf8_1.2.2
 [64] caret_6.0-90        labeling_0.4.2       tidyselect_1.1.2
 [67] rlang_1.0.2         reshape2_1.4.4       munsell_0.5.0
 [70] cellranger_1.1.0    tools_4.1.0          cli_3.2.0
 [73] moments_0.14        generics_0.1.2       broom_0.7.10
 [76] evaluate_0.15       fastmap_1.1.0        yaml_2.3.5
 [79] ModelMetrics_1.2.2.2 knitr_1.37          fs_1.5.2
 [82] nlme_3.1-153        quantreg_5.86        xml2_1.3.3
 [85] compiler_4.1.0      rstudioapi_0.13      png_0.1-7
 [88] ggsignif_0.6.3      reprex_2.0.1         stringi_1.7.6
 [91] nloptr_1.2.2.3      vctrs_0.3.8          pillar_1.7.0
 [94] lifecycle_1.0.1     cowplot_1.1.1        data.table_1.14.2
 [97] conquer_1.2.1       R6_2.5.1             latticeExtra_0.6-29
[100] gridExtra_2.3       parallelly_1.28.1    codetools_0.2-18
```

```
[103] polspline_1.1.19     boot_1.3-28          MASS_7.3-54
[106] assertthat_0.2.1     withr_2.5.0          multcomp_1.4-17
[109] hms_1.1.1            rpart_4.1-15         timeDate_3043.102
[112] class_7.3-19         minqa_1.2.4          rmarkdown_2.13
[115] carData_3.0-4        pROC_1.18.0          lubridate_1.8.0
[118] base64enc_0.1-3
```

References

1. Naimi AI, Moodie EEM, Auger N, et al. Constructing inverse probability weights for continuous exposures: a comparison of methods. *Epidemiology (Cambridge, Mass.).* 2014;25(2):292–299.