

Package ‘AIPW’

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Title Augmented Inverse Probability Weighting

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Description The 'AIPW' package implements the augmented inverse probability weighting, a doubly robust estimator, for average causal effect estimation with user-defined stacked machine learning algorithms. To cite the 'AIPW' package, please use: ``Yongqi Zhong, Edward H. Kennedy, Lisa M. Bodnar, Ashley I. Naimi (2021). AIPW: An R Package for Augmented Inverse Probability Weighted Estimation of Average Causal Effects. American Journal of Epidemiology. <doi:10.1093/aje/kwab207>". Visit: <<https://yqzhong7.github.io/AIPW/>> for more information.

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AIPW

Augmented Inverse Probability Weighting (AIPW)

Description

An R6Class of AIPW for estimating the average causal effects with users' inputs of exposure, outcome, covariates and related libraries for estimating the efficient influence function.

Details

An AIPW object is constructed by `new()` with users' inputs of data and causal structures, then it `fit()` the data using the libraries in `Q.SL.library` and `g.SL.library` with `k_split` cross-fitting, and provides results via the `summary()` method. After using `fit()` and/or `summary()` methods, propensity scores and inverse probability weights by exposure status can be examined with `plot.p_score()` and `plot.ip_weights()`, respectively.

If outcome is missing, analysis assumes missing at random (MAR) by estimating propensity scores of $I(A=a, \text{observed}=1)$ with all covariates W . (`W.Q` and `W.g` are disabled.) Missing exposure is not supported.

See examples for illustration.

Value

AIPW object

Constructor

```
AIPW$new(Y = NULL, A = NULL, W = NULL, W.Q = NULL, W.g = NULL, Q.SL.library = NULL, g.SL.library = NULL, k_split = 10, verbose = TRUE, save.sl.fit = FALSE)
```

Constructor Arguments:

Argument	Type	Details
Y	Integer	A vector of outcome (binary (0, 1) or continuous)
A	Integer	A vector of binary exposure (0 or 1)
W	Data	Covariates for both exposure and outcome models.
W.Q	Data	Covariates for the outcome model (Q).
W.g	Data	Covariates for the exposure model (g).
Q.SL.library	SL.library	Algorithms used for the outcome model (Q).
g.SL.library	SL.library	Algorithms used for the exposure model (g).
k_split	Integer	Number of folds for splitting (Default = 10).
verbose	Logical	Whether to print the result (Default = TRUE)
save.sl.fit	Logical	Whether to save Q.fit and g.fit (Default = FALSE)

Constructor Argument Details:

W, W.Q & W.g It can be a vector, matrix or data.frame. If and only if W == NULL, W would be replaced by W.Q and W.g.

Q.SL.library & g.SL.library Machine learning algorithms from **SuperLearner** libraries or `sl3` learner object (Lrnr_base)

k_split It ranges from 1 to number of observation-1. If k_split=1, no cross-fitting; if k_split>=2, cross-fitting is used (e.g., k_split=10, use 9/10 of the data to estimate and the remaining 1/10 leftover to predict). **NOTE: it's recommended to use cross-fitting.**

save.sl.fit This option allows users to save the fitted sl object (libs\$Q.fit & libs\$g.fit) for debug use. **Warning: Saving the SuperLearner fitted object may cause a substantive storage/memory use.**

Public Methods

Methods	Details	Link
fit()	Fit the data to the AIPW object	fit.AIPW
stratified_fit()	Fit the data to the AIPW object stratified by A	stratified_fit.AIPW
summary()	Summary of the average treatment effects from AIPW	summary.AIPW_base
plot.p_score()	Plot the propensity scores by exposure status	plot.p_score
plot.ip_weights()	Plot the inverse probability weights using truncated propensity scores	plot.ip_weights

Public Variables

Variable	Generated by	Return
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n	Constructor	Number of observations
stratified_fitted	stratified_fit()	Fit the outcome model stratified by exposure status
obs_est	fit() & summary()	Components calculating average causal effects
estimates	summary()	A list of Risk difference, risk ratio, odds ratio
result	summary()	A matrix contains RD, ATT, ATC, RR and OR with their SE and 95%CI
g.plot	plot.p_score()	A density plot of propensity scores by exposure status
ip_weights.plot	plot.ip_weights()	A box plot of inverse probability weights
libs	fit()	SuperLearner or sl3 libraries and their fitted objects
sl.fit	Constructor	A wrapper function for fitting SuperLearner or sl3
sl.predict	Constructor	A wrapper function using sl.fit to predict

Public Variable Details:

stratified_fit An indicator for whether the outcome model is fitted stratified by exposure status in the fit() method. Only when using stratified_fit() to turn on stratified_fit = TRUE, summary outputs average treatment effects among the treated and the controls.

obs_est After using fit() and summary() methods, this list contains the propensity scores (p_score), counterfactual predictions (mu, mu1 & mu0) and efficient influence functions (aipw_eif1 & aipw_eif0) for later average treatment effect calculations.

g.plot This plot is generated by ggplot2::geom_density

ip_weights.plot This plot uses truncated propensity scores stratified by exposure status (ggplot2::geom_boxplot)

References

Zhong Y, Kennedy EH, Bodnar LM, Naimi AI (2021). AIPW: An R Package for Augmented Inverse Probability Weighted Estimation of Average Causal Effects. *American Journal of Epidemiology*.

Robins JM, Rotnitzky A (1995). Semiparametric efficiency in multivariate regression models with missing data. *Journal of the American Statistical Association*.

Chernozhukov V, Chetverikov V, Demirer M, et al (2018). Double/debiased machine learning for treatment and structural parameters. *The Econometrics Journal*.

Kennedy EH, Sjolander A, Small DS (2015). Semiparametric causal inference in matched cohort studies. *Biometrika*.

Examples

```
library(SuperLearner)
library(ggplot2)

#create an object
aipw_sl <- AIPW$new(Y=rbinom(100,1,0.5), A=rbinom(100,1,0.5),
                  W.Q=rbinom(100,1,0.5), W.g=rbinom(100,1,0.5),
                  Q.SL.library="SL.mean",g.SL.library="SL.mean",
                  k_split=1,verbose=FALSE)

#fit the object
aipw_sl$fit()
# or use `aipw_sl$stratified_fit()` to estimate ATE and ATT/ATC
```

```
#calculate the results
aipw_sl$summary(g.bound = 0.025)

#check the propensity scores by exposure status after truncation
aipw_sl$plot.p_score()
```

AIPW_base	<i>Augmented Inverse Probability Weighting Base Class (AIPW_base)</i>
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Description

A base class for AIPW that implements the common methods, such as `summary()` and `plot.p_score()`, inherited by [AIPW](#) and [AIPW_tmle](#) class

Format

R6 object.

Value

AIPW base object

See Also

[AIPW](#) and [AIPW_tmle](#)

AIPW_nuis	<i>Augmented Inverse Probability Weighting (AIPW) uses tmle or tmle3 as inputs</i>
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Description

AIPW_nuis class for users to manually input nuisance functions (estimates from the exposure and the outcome models)

Details

Create an AIPW_nuis object that uses users' input nuisance functions from the exposure model $P(A|W)$, and the outcome models $P(Y|do(A = 0), W)$ and $P(Y|do(A = 1), W, Q)$:

$$\psi(a) = E[I(A = a)/P(A = a|W)] * [Y - P(Y = 1|A, W)] + P(Y = 1|do(A = a), W)$$

Note: If outcome is missing, replace (A=a) with (A=a, observed=1) when estimating the propensity scores.

Value

AIPW_nuis object

Constructor

```
AIPW$new(Y = NULL, A = NULL, tmle_fit = NULL, verbose = TRUE)
```

Constructor Arguments:

Argument	Type	Details
Y	Integer	A vector of outcome (binary (0, 1) or continuous)
A	Integer	A vector of binary exposure (0 or 1)
mu0	Numeric	User input of $P(Y = 1 do(A = 0), W_Q)$
mu1	Numeric	User input of $P(Y = 1 do(A = 1), W_Q)$
raw_p_score	Numeric	User input of $P(A = a W_g)$
verbose	Logical	Whether to print the result (Default = TRUE)
stratified_fitted	Logical	Whether mu0 & mu1 was estimated only using A=0 & A=1 (Default = FALSE)

Public Methods

Methods	Details	Link
summary()	Summary of the average treatment effects from AIPW	summary.AIPW_base
plot.p_score()	Plot the propensity scores by exposure status	plot.p_score
plot.ip_weights()	Plot the inverse probability weights using truncated propensity scores	plot.ip_weights

Public Variables

Variable	Generated by	Return
n	Constructor	Number of observations
obs_est	Constructor	Components calculating average causal effects
estimates	summary()	A list of Risk difference, risk ratio, odds ratio
result	summary()	A matrix contains RD, ATT, ATC, RR and OR with their SE and 95%CI
g.plot	plot.p_score()	A density plot of propensity scores by exposure status
ip_weights.plot	plot.ip_weights()	A box plot of inverse probability weights

Public Variable Details:

`stratified_fit` An indicator for whether the outcome model is fitted stratified by exposure status in the `fit()` method. Only when using `stratified_fit()` to turn on `stratified_fit = TRUE`, summary outputs average treatment effects among the treated and the controls.

`obs_est` This list includes propensity scores (`p_score`), counterfactual predictions (`mu`, `mu1` & `mu0`) and efficient influence functions (`aipw_eif1` & `aipw_eif0`)

`g.plot` This plot is generated by `ggplot2::geom_density`

`ip_weights.plot` This plot uses truncated propensity scores stratified by exposure status (`ggplot2::geom_boxplot`)

AIPW_tmle	<i>Augmented Inverse Probability Weighting (AIPW) uses tmle or tmle3 as inputs</i>
-----------	--

Description

AIPW_tmle class uses a fitted tmle or tmle3 object as input

Details

Create an AIPW_tmle object that uses the estimated efficient influence function from a fitted tmle or tmle3 object

Value

AIPW_tmle object

Constructor

AIPW\$new(Y = NULL, A = NULL, tmle_fit = NULL, verbose = TRUE)

Constructor Arguments:

Argument	Type	Details
Y	Integer	A vector of outcome (binary (0, 1) or continuous)
A	Integer	A vector of binary exposure (0 or 1)
tmle_fit	Object	A fitted tmle or tmle3 object
verbose	Logical	Whether to print the result (Default = TRUE)

Public Methods

Methods	Details	Link
summary()	Summary of the average treatment effects from AIPW	summary.AIPW_base
plot.p_score()	Plot the propensity scores by exposure status	plot.p_score
plot.ip_weights()	Plot the inverse probability weights using truncated propensity scores	plot.ip_weights

Public Variables

Variable	Generated by	Return
n	Constructor	Number of observations
obs_est	Constructor	Components calculating average causal effects
estimates	summary()	A list of Risk difference, risk ratio, odds ratio
result	summary()	A matrix contains RD, ATT, ATC, RR and OR with their SE and 95%CI

g.plot	plot.p_score()	A density plot of propensity scores by exposure status
ip_weights.plot	plot.ip_weights()	A box plot of inverse probability weights

Public Variable Details:

obs_est This list extracts from the fitted tmle or tmle3 object. It includes propensity scores (p_score), counterfactual predictions (mu, mu1 & mu0) and efficient influence functions (aipw_eif1 & aipw_eif0)

g.plot This plot is generated by ggplot2::geom_density

ip_weights.plot This plot uses truncated propensity scores stratified by exposure status (ggplot2::geom_boxplot)

Examples

```
## Not run:
vec <- function() sample(0:1,100,replace = TRUE)
df <- data.frame(replicate(4,vec()))
names(df) <- c("A","Y","W1","W2")

## From tmle
library(tmle)
library(SuperLearner)
tmle_fit <- tmle(Y=df$Y,A=df$A,W=subset(df,select=c("W1","W2")),
               Q.SL.library="SL.glm",
               g.SL.library="SL.glm",
               family="binomial")
AIPW_tmle$new(A=df$A,Y=df$Y,tmle_fit = tmle_fit,verbose = TRUE)$summary()

## From tmle3
# tmle3 simple implementation
library(tmle3)
library(sl3)
node_list <- list(A = "A",Y = "Y",W = c("W1","W2"))
or_spec <- tmle_OR(baseline_level = "0",contrast_level = "1")
tmle_task <- or_spec$make_tmle_task(df,node_list)
lrnr_glm <- make_learner(Lrnr_glm)
sl <- Lrnr_sl$new(learners = list(lrnr_glm))
learner_list <- list(A = sl, Y = sl)
tmle3_fit <- tmle3(or_spec, data=df, node_list, learner_list)

# parse tmle3_fit into AIPW_tmle class
AIPW_tmle$new(A=df$A,Y=df$Y,tmle_fit = tmle3_fit,verbose = TRUE)$summary()

## End(Not run)
```

Description

A wrapper function for `AIPW$new()$fit()$summary()`

Usage

```
aipw_wrapper(
  Y,
  A,
  verbose = TRUE,
  W = NULL,
  W.Q = NULL,
  W.g = NULL,
  Q.SL.library,
  g.SL.library,
  k_split = 10,
  g.bound = 0.025,
  stratified_fit = FALSE
)
```

Arguments

Y	Outcome (binary integer: 0 or 1)
A	Exposure (binary integer: 0 or 1)
verbose	Whether to print the result (logical; Default = FALSE)
W	covariates for both exposure and outcome models (vector, matrix or data.frame). If null, this function will seek for inputs from W.Q and W.g.
W.Q	Only valid when W is null, otherwise it would be replaced by W. Covariates for outcome model (vector, matrix or data.frame).
W.g	Only valid when W is null, otherwise it would be replaced by W. Covariates for exposure model (vector, matrix or data.frame)
Q.SL.library	SuperLearner libraries or sl3 learner object (Lrn_base) for outcome model
g.SL.library	SuperLearner libraries or sl3 learner object (Lrn_base) for exposure model
k_split	Number of splitting (integer; range: from 1 to number of observation-1): if k_split=1, no cross-fitting; if k_split>=2, cross-fitting is used (e.g., k_split=10, use 9/10 of the data to estimate and the remaining 1/10 leftover to predict). NOTE: it's recommended to use cross-fitting.
g.bound	Value between [0,1] at which the propensity score should be truncated. Defaults to 0.025.
stratified_fit	An indicator for whether the outcome model is fitted stratified by exposure status in the fit() method. Only when using stratified_fit() to turn on stratified_fit = TRUE, summary outputs average treatment effects among the treated and the controls.

Value

A fitted AIPW object with summarised results

See Also[AIPW](#)**Examples**

```
library(SuperLearner)
aipw_sl <- aipw_wrapper(Y=rbinom(100,1,0.5), A=rbinom(100,1,0.5),
                       W.Q=rbinom(100,1,0.5), W.g=rbinom(100,1,0.5),
                       Q.SL.library="SL.mean",g.SL.library="SL.mean",
                       k_split=1,verbose=FALSE)
```

eager_sim_obs

*Simulated Observational Study***Description**

Datasets were simulated using baseline covariates (sampling with replacement) from the Effects of Aspirin in Gestation and Reproduction (EAGeR) study. Data generating mechanisms were described in our manuscript (Zhong et al. (inpreparation), Am. J. Epidemiol.). True marginal causal effects on risk difference, log risk ratio and log odds ratio scales were attached to the dataset attributes (true_rd, true_logrr,true_logor).

Usage

```
data(eager_sim_obs)
```

Format

An object of class data.frame with 200 rows and 8 columns:

sim_Y binary, simulated outcome which is condition on all other covariates in the dataset

sim_A binary, simulated exposure which is conditon on all other covarites expect sim_Y.

eligibility binary, indicator of the eligibility stratum

loss_num count, number of prior pregnancy losses

age continuous, age in years

time_try_pregnant count, months of conception attempts prior to randomization

BMI continuous, body mass index

meanAP continuous, mean arterial blood pressure

References

Schisterman, E.F., Silver, R.M., Leshner, L.L., Faraggi, D., Wactawski-Wende, J., Townsend, J.M., Lynch, A.M., Perkins, N.J., Mumford, S.L. and Galai, N., 2014. Preconception low-dose aspirin and pregnancy outcomes: results from the EAGeR randomised trial. *The Lancet*, 384(9937), pp.29-36.

Zhong, Y., Naimi, A.I., Kennedy, E.H., (In preparation). AIPW: An R package for Augmented Inverse Probability Weighted Estimation of Average Causal Effects. *American Journal of Epidemiology*

See Also[eager_sim_rct](#)

eager_sim_rct	<i>Simulated Randomized Trial</i>
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Description

Datasets were simulated using baseline covariates (sampling with replacement) from the Effects of Aspirin in Gestation and Reproduction (EAGeR) study.

Usage

```
data(eager_sim_rct)
```

Format

An object of class `data.frame` with 1228 rows and 8 columns:

sim_Y binary, simulated outcome which is condition on all other covariates in the dataset

sim_T binary, simulated treatment which is condition on eligibility only.

eligibility binary, indicator of the eligibility stratum

loss_num count, number of prior pregnancy losses

age continuous, age in years

time_try_pregnant count, months of conception attempts prior to randomization

BMI continuous, body mass index

meanAP continuous, mean arterial blood pressure

References

Schisterman, E.F., Silver, R.M., Leshner, L.L., Faraggi, D., Wactawski-Wende, J., Townsend, J.M., Lynch, A.M., Perkins, N.J., Mumford, S.L. and Galai, N., 2014. Preconception low-dose aspirin and pregnancy outcomes: results from the EAGeR randomised trial. *The Lancet*, 384(9937), pp.29-36.

Zhong, Y., Naimi, A.I., Kennedy, E.H., (In preparation). AIPW: An R package for Augmented Inverse Probability Weighted Estimation of Average Causal Effects. *American Journal of Epidemiology*

See Also[eager_sim_obs](#)

fit	<i>Fit the data to the AIPW object</i>
-----	--

Description

Fitting the data into the [AIPW](#) object with/without cross-fitting to estimate the efficient influence functions

Value

A fitted [AIPW](#) object with `obs_est` and `libs` (public variables)

R6 Usage

`$fit()`

See Also

[AIPW](#)

plot.ip_weights	<i>Plot the inverse probability weights using truncated propensity scores by exposure status</i>
-----------------	--

Description

Plot and check the balance of propensity scores by exposure status

Value

`ip_weights.plot` (public variable): A box plot of inverse probability weights using truncated propensity scores by exposure status (`ggplot2::geom_boxplot`)

R6 Usage

`$plot.ip_weights()`

See Also

[AIPW](#) and [AIPW_tmle](#)

plot.p_score	<i>Plot the propensity scores by exposure status</i>
--------------	--

Description

Plot and check the balance of propensity scores by exposure status

Value

g.plot (public variable): A density plot of propensity scores by exposure status (ggplot2::geom_density)

R6 Usage

\$plot.p_plot()

See Also

[AIPW](#) and [AIPW_tmle](#)

Repeated	<i>Repeated Crossfitting Procedure for AIPW</i>
----------	---

Description

An R6Class that allows repeated crossfitting procedure for an [AIPW](#) object

Details

See examples for illustration.

Value

AIPW object

Constructor

Repeated\$new(aipw_obj = NULL)

Constructor Arguments:

Argument	Type	Details
aipw_obj	AIPW object	an AIPW object

Public Methods

Methods	Details	Link
repfit()	Fit the data to the AIPW object num_reps times	repfit.Repeated
summary_median()	Summary (median) of estimates from the repfit()	summary_median.Repeated

Public Variables

Variable	Generated by	Return
repeated_estimates	repfit()	A data.frame of estimates from num_reps cross-fitting
repeated_results	summary_median()	A list of summarised estimates
result	summary_median()	A data.frame of summarised estimates

Public Variable Details:

repeated_estimates Estimates from num_reps cross-fitting.

result Summarised estimates from ‘repeated_estimates’ using median methods.

References

Zhong Y, Kennedy EH, Bodnar LM, Naimi AI (2021). AIPW: An R Package for Augmented Inverse Probability Weighted Estimation of Average Causal Effects. *American Journal of Epidemiology*.

Robins JM, Rotnitzky A (1995). Semiparametric efficiency in multivariate regression models with missing data. *Journal of the American Statistical Association*.

Chernozhukov V, Chetverikov V, Demirer M, et al (2018). Double/debiased machine learning for treatment and structural parameters. *The Econometrics Journal*.

Kennedy EH, Sjolander A, Small DS (2015). Semiparametric causal inference in matched cohort studies. *Biometrika*.

Examples

```
library(SuperLearner)
library(ggplot2)

#create an object
aipw_sl <- AIPW$new(Y=rbinom(100,1,0.5), A=rbinom(100,1,0.5),
                  W.Q=rbinom(100,1,0.5), W.g=rbinom(100,1,0.5),
                  Q.SL.library="SL.mean",g.SL.library="SL.mean",
                  k_split=2,verbose=FALSE)

#create a repeated crossfitting object from the previous step
repeated_aipw_sl <- Repeated$new(aipw_sl)

#fit repetitively (stratified = TRUE will use stratified_fit() method in AIPW class)
```

```
repeated_aipw_sl$refit(num_reps = 3, stratified = FALSE)

#summarise the results
repeated_aipw_sl$summary_median()
```

refit*Fit the data to the [AIPW](#) object repeatedly*

Description

Fitting the data into the [AIPW](#) object with cross-fitting repeatedly to obtain multiple estimates from repetitions to avoid randomness due to splits in cross-fitting

Arguments

num_reps	Integer. Number of repetition of cross-fitting procedures (<code>fit()</code> or <code>stratified_fit()</code> see below).
stratified	Boolean. <code>stratified = TRUE</code> will use <code>stratified_fit()</code> in the AIPW object to cross-fitting.

Value

A [Repeated](#) object with `repeated_estimates` (estimates from `num_reps` times repetition)

R6 Usage

```
$refit(num_reps = 20, stratified = FALSE)
```

References

Chernozhukov V, Chetverikov V, Demirer M, et al (2018). Double/debiased machine learning for treatment and structural parameters. *The Econometrics Journal*.

See Also

[Repeated](#) and [AIPW](#)

stratified_fit	<i>Fit the data to the AIPW object stratified by A for the outcome model</i>
----------------	--

Description

Fitting the data into the [AIPW](#) object with/without cross-fitting to estimate the efficient influence functions. Outcome model is fitted, stratified by exposure status A

Value

A fitted [AIPW](#) object with obs_est and libs (public variables)

R6 Usage

```
$stratified_fit.AIPW()
```

See Also

[AIPW](#)

summary	<i>Summary of the average treatment effects from AIPW</i>
---------	---

Description

Calculate average causal effects in RD, RR and OR in the fitted [AIPW](#) or [AIPW_tmle](#) object using the estimated efficient influence functions

Arguments

g.bound	Value between [0,1] at which the propensity score should be truncated. Propensity score will be truncated to $[g.bound, 1 - g.bound]$ when one g.bound value is provided, or to $[\min(g.bound), \max(g.bound)]$ when two values are provided. Defaults to 0.025.
---------	--

Value

estimates and result (public variables): Risks, Average treatment effect in RD, RR and OR.

R6 Usage

```
$summary(g.bound = 0.025)
$summary(g.bound = c(0.025, 0.975))
```

See Also

[AIPW](#) and [AIPW_tmle](#)

summary_median	<i>Summary of the repeated_estimates from repfit() in the Repeated object using median methods.</i>
----------------	---

Description

From repeated_estimates, calculate the median estimate (median(Estimates)), median SE (median(SE)), SE adjusting for variations across num_reps times, and 95% CI using SE adjusting for SE adjusted for variability.

Value

repeated_results and result (public variables).

R6 Usage

```
$summary_median.Repeated()
```

References

Chernozhukov V, Chetverikov V, Demirer M, et al (2018). Double/debiased machine learning for treatment and structural parameters. *The Econometrics Journal*.

See Also

[Repeated](#) and [AIPW](#)

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