

# Introduction to Uplift Modeling

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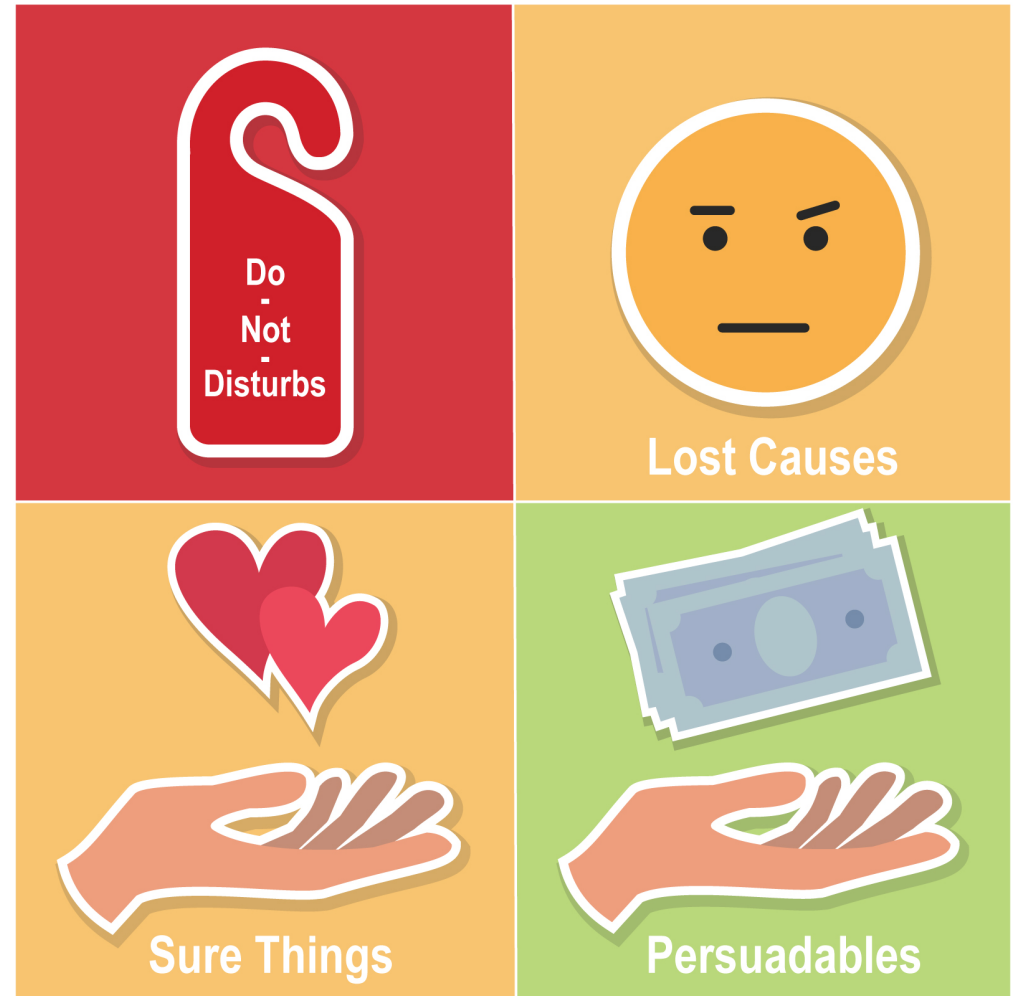
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**PyConDE & PyData Berlin 2022**



# Motivation

How can we optimally select customers to be treated by marketing incentives?



We can not **send** and **not send** incentives to the same customers at the same time



# What is Uplift Modeling?

From [Gutierrez, P., & Gérardy, J. Y. \(2017\). "Causal Inference and Uplift Modelling: A Review of the Literature"](#)

- **Uplift modeling refers to the set of techniques used to model the incremental impact of an action or treatment on a customer outcome.**
- **Uplift modeling is therefore both a Causal Inference problem and a Machine Learning one.**

# Conditional Average Treatment Effect

- Let  $Y_i^1$  denote person  $i$ 's outcome when it receives the treatment and  $Y_i^0$  when it does not receive the treatment.
- We are interested in understanding the *causal effect*  $Y_i^1 - Y_i^0$  and the *conditional average treatment effect*  $CATE = E[Y_i^1 | X_i] - E[Y_i^0 | X_i]$ , where  $X_i$  is a feature vector of the  $i$ -th person.
- **However, we can not observe them!** 😞

# Uplift

Let  $W_i$  is a binary variable indicating whether person  $i$  received the treatment, so that

$$Y_i^{obs} = Y_i^1 W_i + (1 - W_i) Y_i^0$$

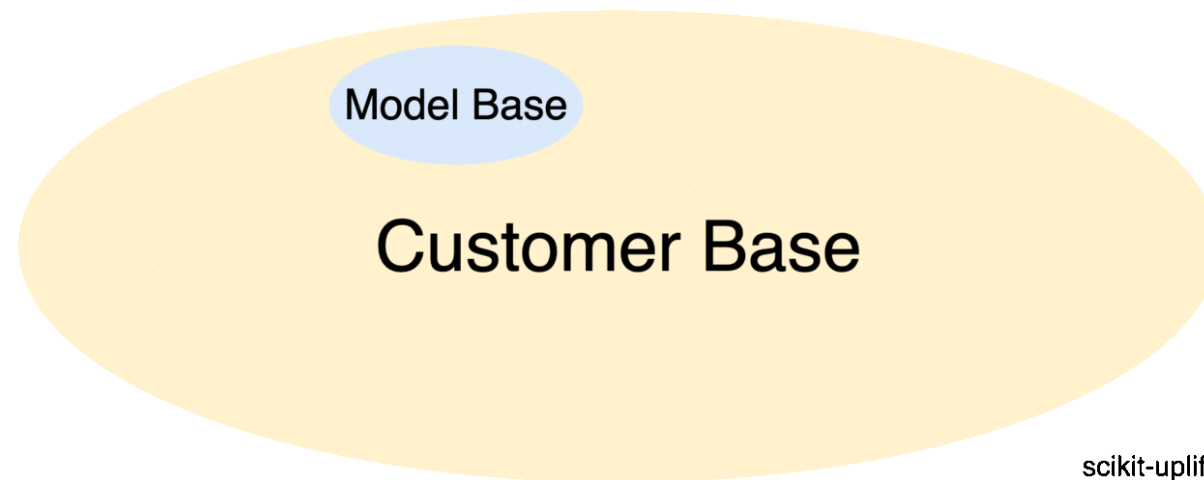
## Unconfoundedness Assumption

If we **assume** that the treatment assignment  $W_i$  is independent of  $Y_i^1$  and  $Y_i^0$  conditional on  $X_i$ , then we can estimate the *CATE* from observational data by computing the empirical counterpart:

$$\mathbf{uplift} = \widehat{CATE} = E[Y_i | X_i, W_i = 1] - E[Y_i | X_i, W_i = 0]$$

# Data Collection

1. Randomly subset the customer base to create a representative model base.



scikit-uptift

# Estimating Uplift

- **Meta Algorithms** ← Today
- **The Class Transformation Method**
- **Direct measurements (e.g. trees)**



# S-Learner

## Step 1: Training

$$\underbrace{\begin{pmatrix} x_{11} & \cdots & x_{1k} & w_1 \\ \vdots & \ddots & \vdots & \vdots \\ x_{n1} & \cdots & x_{nk} & w_n \end{pmatrix}}_{X \oplus W} \xrightarrow{\mu} \begin{pmatrix} y_1 \\ \vdots \\ y_n \end{pmatrix}$$

## Step 2: Uplift Prediction

$$\widehat{\text{uplift}} = \hat{\mu} \begin{pmatrix} x_{11} & \cdots & x_{1k} & 1 \\ \vdots & \ddots & \vdots & \vdots \\ x_{m1} & \cdots & x_{mk} & 1 \end{pmatrix} - \hat{\mu} \begin{pmatrix} x_{11} & \cdots & x_{1k} & 0 \\ \vdots & \ddots & \vdots & \vdots \\ x_{m1} & \cdots & x_{mk} & 0 \end{pmatrix}$$

# T-Learner

## Step 1: Training

$$\underbrace{\begin{pmatrix} x_{11} & \cdots & x_{1k} \\ \vdots & \ddots & \vdots \\ x_{n_C 1} & \cdots & x_{n_C k} \end{pmatrix}}_{X^C := X|_{\text{control}}} \xrightarrow{\mu_C} \begin{pmatrix} y_1 \\ \vdots \\ y_{n_C} \end{pmatrix}$$
$$\underbrace{\begin{pmatrix} x_{11} & \cdots & x_{1k} \\ \vdots & \ddots & \vdots \\ x_{n_T 1} & \cdots & x_{n_T k} \end{pmatrix}}_{X^T := X|_{\text{treatment}}} \xrightarrow{\mu_T} \begin{pmatrix} y_1 \\ \vdots \\ y_{n_T} \end{pmatrix}$$

# T-Learner

## Step 2: Uplift Prediction

$$\widehat{\text{uplift}} = \hat{\mu}_T \begin{pmatrix} x_{11} & \cdots & x_{1k} \\ \vdots & \ddots & \vdots \\ x_{11} & \cdots & x_{mk} \end{pmatrix} - \hat{\mu}_C \begin{pmatrix} x_{11} & \cdots & x_{1k} \\ \vdots & \ddots & \vdots \\ x_{11} & \cdots & x_{mk} \end{pmatrix}$$

# X-Learner

Step 1: Training: Same as T-Learner

Step 2: Compute imputed treatment effects

$$\tilde{D}^T := \begin{pmatrix} y_1 \\ \vdots \\ y_{n_T} \end{pmatrix} - \hat{\mu}_C \begin{pmatrix} x_{11} & \cdots & x_{1k} \\ \vdots & \ddots & \vdots \\ x_{11} & \cdots & x_{n_T k} \end{pmatrix}$$

$$\tilde{D}^C := \hat{\mu}_T \begin{pmatrix} x_{11} & \cdots & x_{1k} \\ \vdots & \ddots & \vdots \\ x_{11} & \cdots & x_{n_C k} \end{pmatrix} - \begin{pmatrix} y_1 \\ \vdots \\ y_{n_C} \end{pmatrix}$$

# X-Learner

## Step 3: Train with different targets

$$\underbrace{\begin{pmatrix} x_{11} & \cdots & x_{1k} \\ \vdots & \ddots & \vdots \\ x_{n_C 1} & \cdots & x_{n_C k} \end{pmatrix}}_{X|_{\text{control}}} \xrightarrow{\tau_C} \begin{pmatrix} \tilde{D}_1^C \\ \vdots \\ \tilde{D}_{n_T}^C \end{pmatrix}$$
$$\underbrace{\begin{pmatrix} x_{11} & \cdots & x_{1k} \\ \vdots & \ddots & \vdots \\ x_{n_C 1} & \cdots & x_{n_C k} \end{pmatrix}}_{X|_{\text{treatment}}} \xrightarrow{\tau_T} \begin{pmatrix} \tilde{D}_1^T \\ \vdots \\ \tilde{D}_{n_T}^T \end{pmatrix}$$

# X-Learner

## Step 4: Uplift Prediction

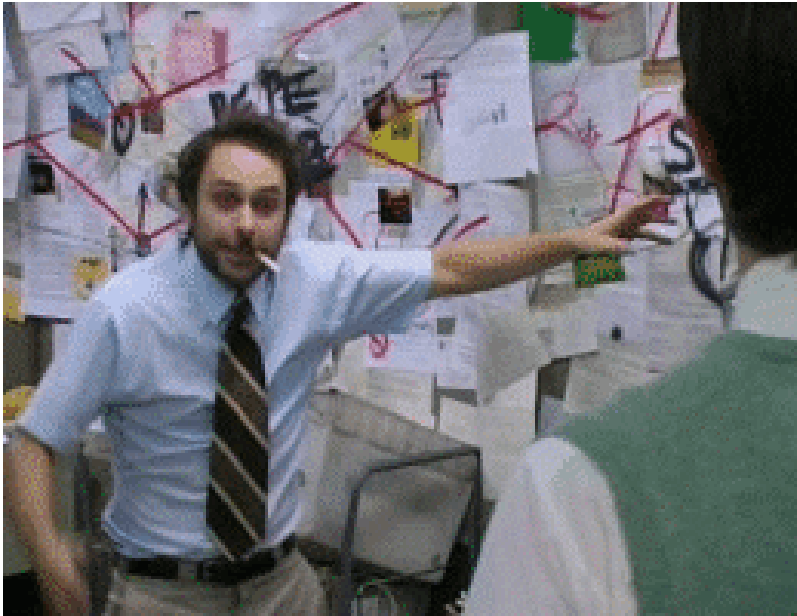
$$\widehat{\text{uplift}} = g(x)\hat{\tau}_C(x) + (1 - g(x))\hat{\tau}_T(x)$$

where  $g(x) \in [0, 1]$  is a weight function.

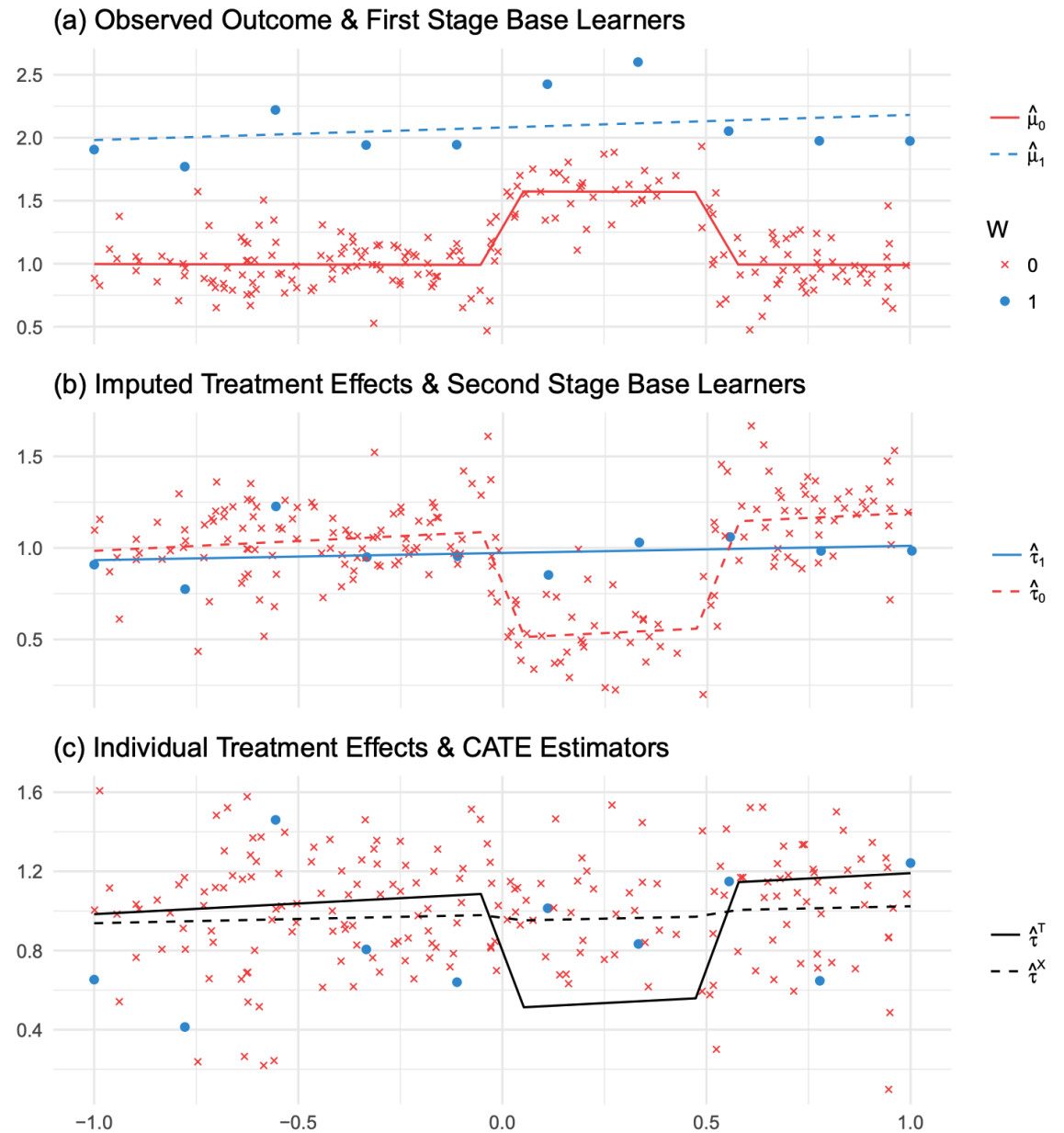
**Remark:** A common choice for  $g(x)$  is an estimator of the **propensity score**, which is defined as the probability of treatment given the covariates  $X$ , i.e.  $p(W_i = 1|X_i)$ .

# Intuition behind the X-Learner

We use an simulated example where we know the uplift is exactly 1.

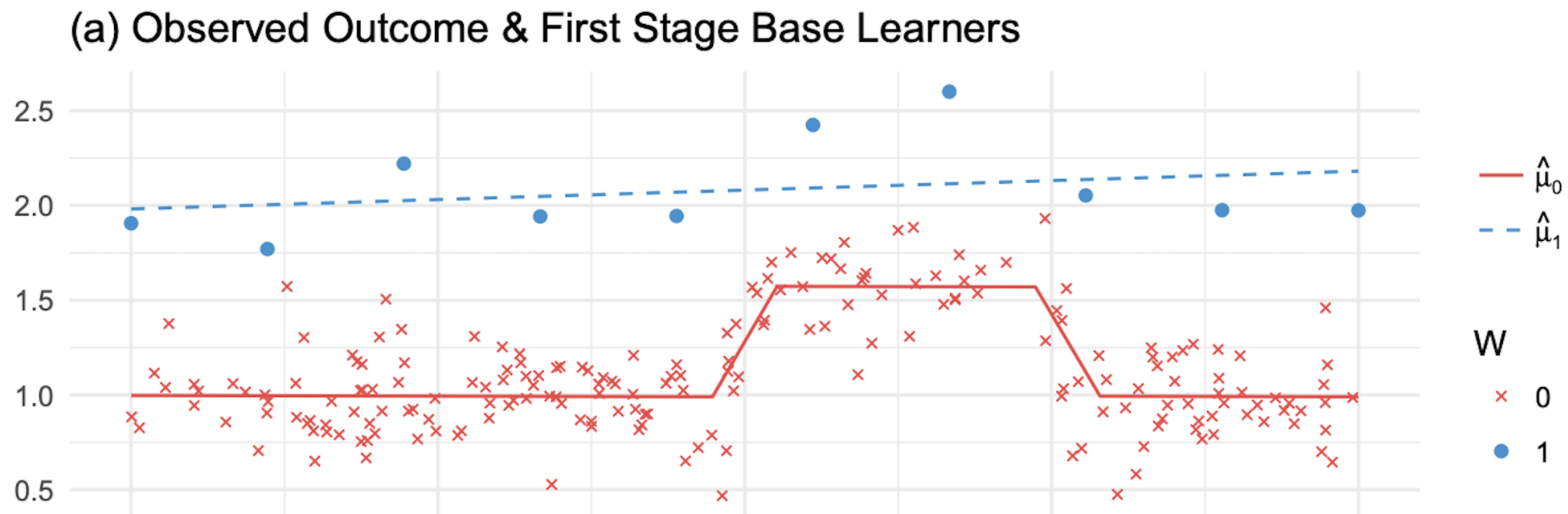


Taken from Sören, R, et.al. (2019) "*Meta-learners for Estimating Heterogeneous Treatment Effects using Machine Learning*"



# X-Learner Step 1 (same as T-Learner):

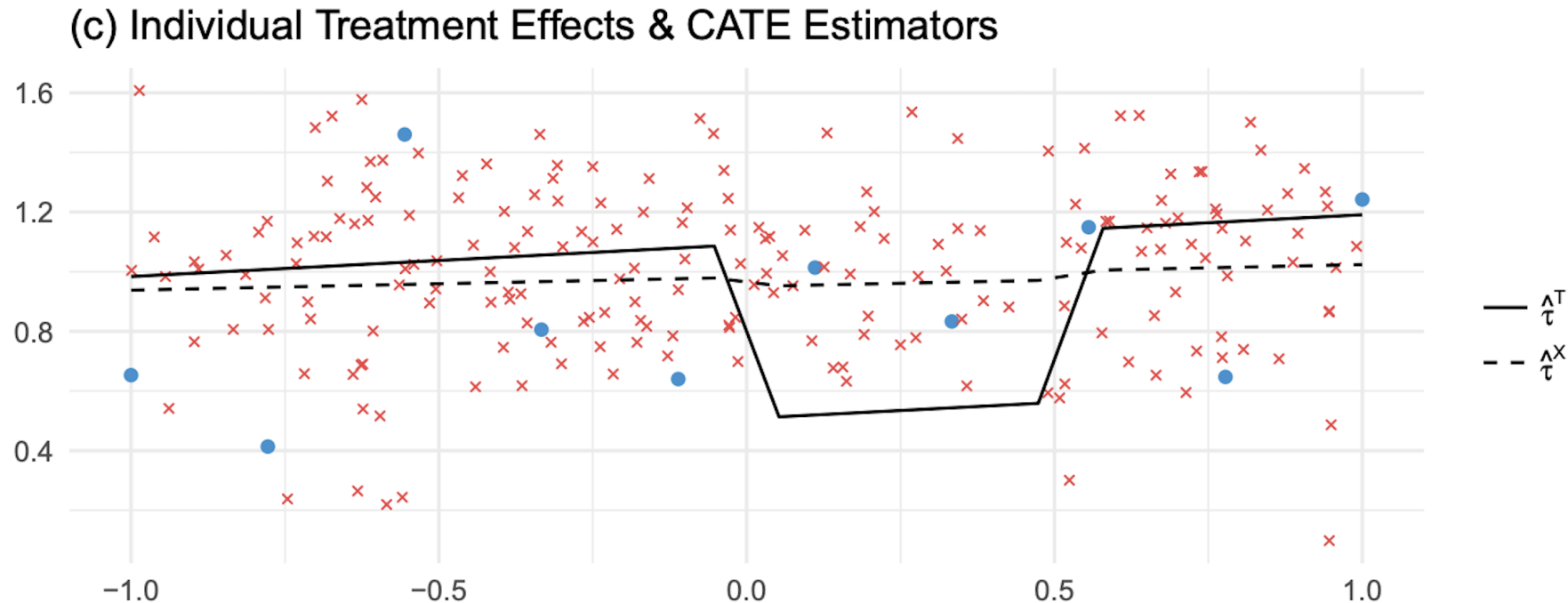
Model fit for control (red) and treatment (blue) groups.





# T-Learner Estimation:

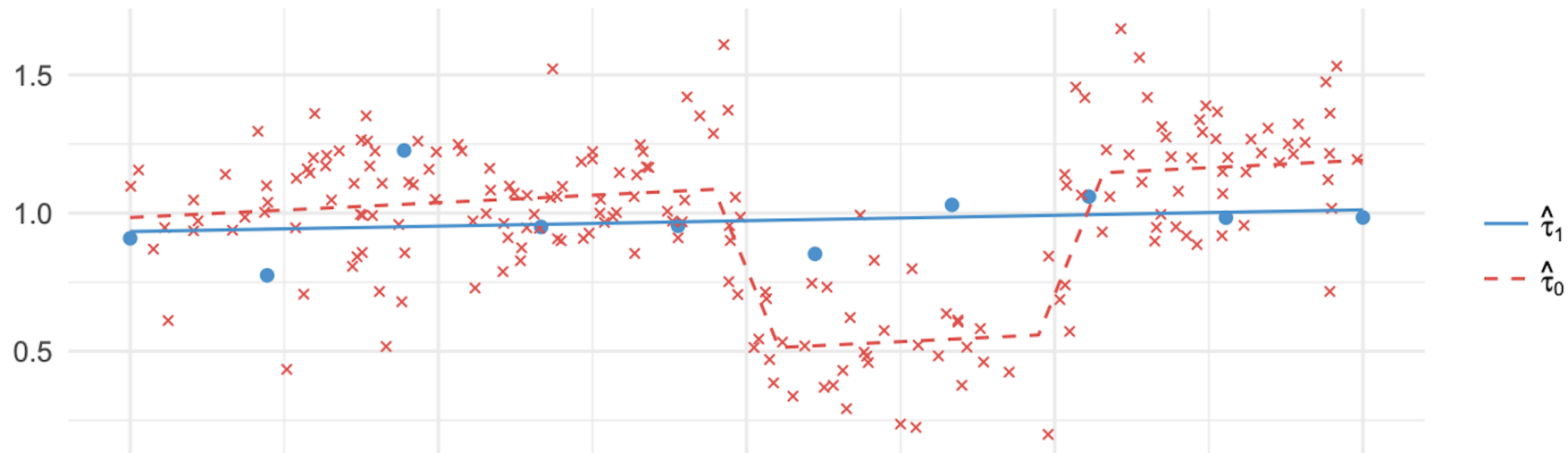
- The solid line represents the difference between the model fit for the control group and the treatment groups.
- The estimation is not good as the treatment group is very small.



# Imputed Treatment Effects:

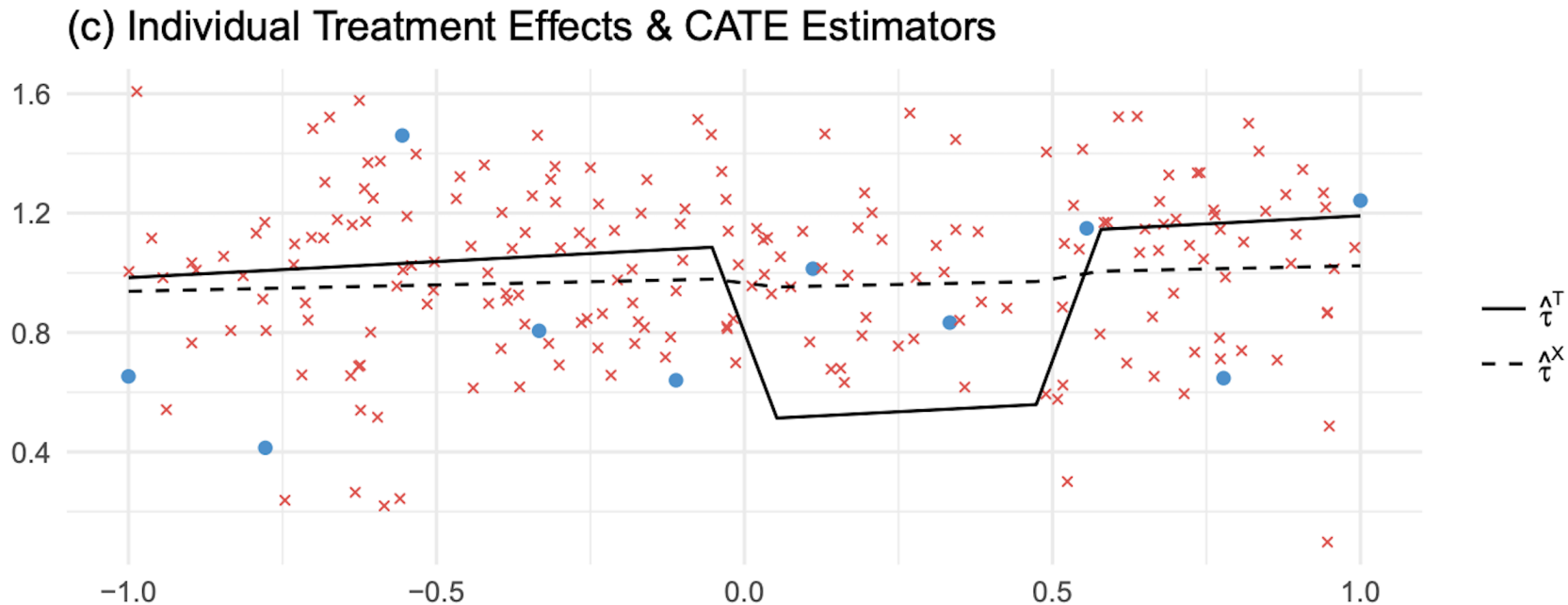
$$\tilde{D}^T = Y^T - \hat{\mu}_C(X^T)$$
$$\tilde{D}^C = \hat{\mu}_T(X^C) - Y^C$$

(b) Imputed Treatment Effects & Second Stage Base Learners



# X-Learner Estimation:

- The dashed line represents the X-Learner estimation.
- It combines the fit from the imputed effects by using an estimator of the *propensity score*, i.e.  $g(x) = \hat{e}(x)$ . In this example  $\hat{e}(x)$  will be small as we have much more observations in the control group. Hence the estimated uplift will be close to  $\hat{\tau}^T$ .



# Some python implementations

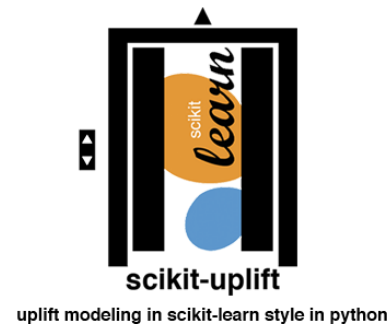
- `causalml`



- `EconML`



- `scikit-uplift`



# Python code: Example

```
from causalml.inference.meta import BaseTClassifier
from sklearn.ensemble import HistGradientBoostingClassifier

# define ml model
learner = HistGradientBoostingClassifier()

# set meta-model
t_learner = BaseTClassifier(learner=learner)

# compute ate
t_ate_lwr, t_ate, t_ate_upr = t_learner.estimate_ate(X=x, treatment=w, y=y)

# predict treatment effects
t_learner.predict(X=x)

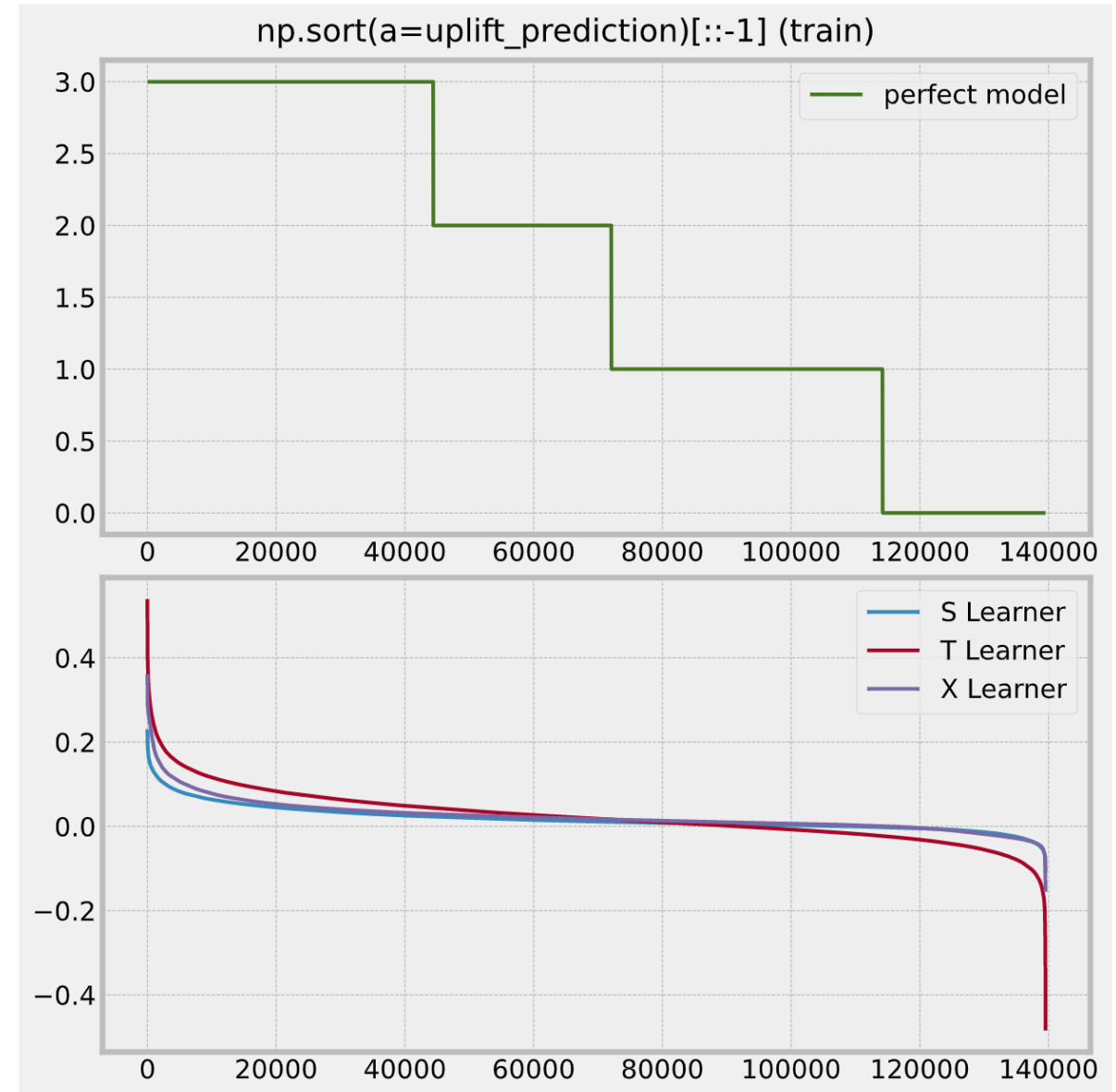
# access ml models
t_learner.models_c[1]
t_learner.models_t[1]
```

# Uplift Model Evaluation

A **perfect model** assigns higher scores to all treated individuals with positive outcomes than any individuals with negative outcomes.

```
# Control Responders
cr_num = np.sum((y_true == 1) & (treatment == 0))
# Treated Non-Responders
tn_num = np.sum((y_true == 0) & (treatment == 1))

summand = y_true if cr_num > tn_num else treatment
perfect_uplift = 2 * (y_true == treatment) + summand
```



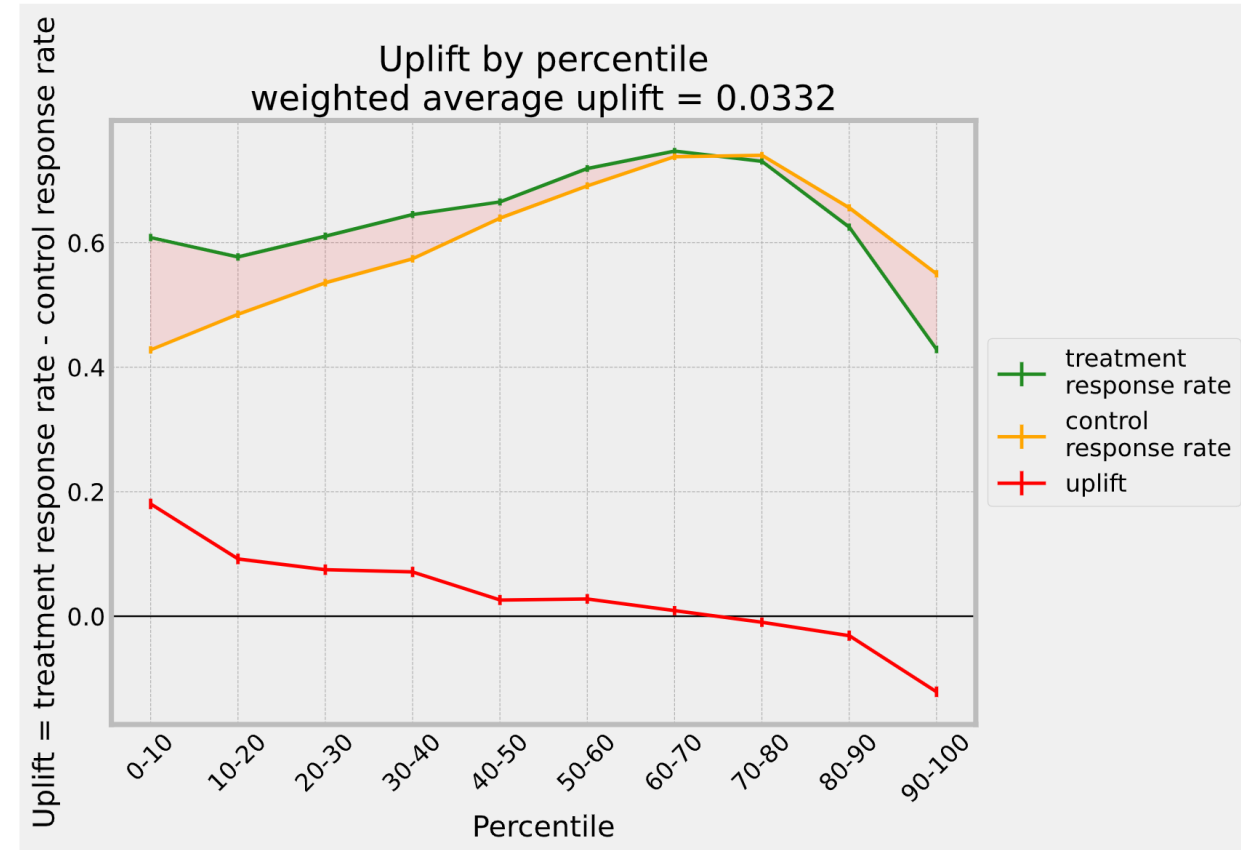
# Uplift Evaluation: Uplift by percentile

1. Sort uplift predictions by decreasing order.
2. Predict uplift for both treated and control observations
3. Compute the average prediction per percentile in both groups.
4. The difference between those averages is taken for each percentile.

	n_treatment	n_control	response_rate_treatment	response_rate_control	uplift
percentile					
0-10	6870	7082	0.608297	0.427845	0.180452
10-20	6974	6978	0.577144	0.485096	0.092048
20-30	7082	6870	0.610421	0.535662	0.074758
30-40	7200	6751	0.645278	0.574137	0.071141
40-50	7086	6865	0.665538	0.639476	0.026062
50-60	6959	6992	0.719213	0.691362	0.027851
60-70	6955	6996	0.747088	0.738136	0.008952
70-80	7002	6949	0.730934	0.740538	-0.009604
80-90	6927	7024	0.624946	0.656179	-0.031233
90-100	6667	7284	0.428679	0.550110	-0.121431
total	69722	69791	0.636743	0.603531	0.033213

# Uplift Evaluation: Uplift by percentile

A well performing model would have large values in the first percentiles and decreasing values for larger ones





# Uplift Evaluation: Cumulative gain chart

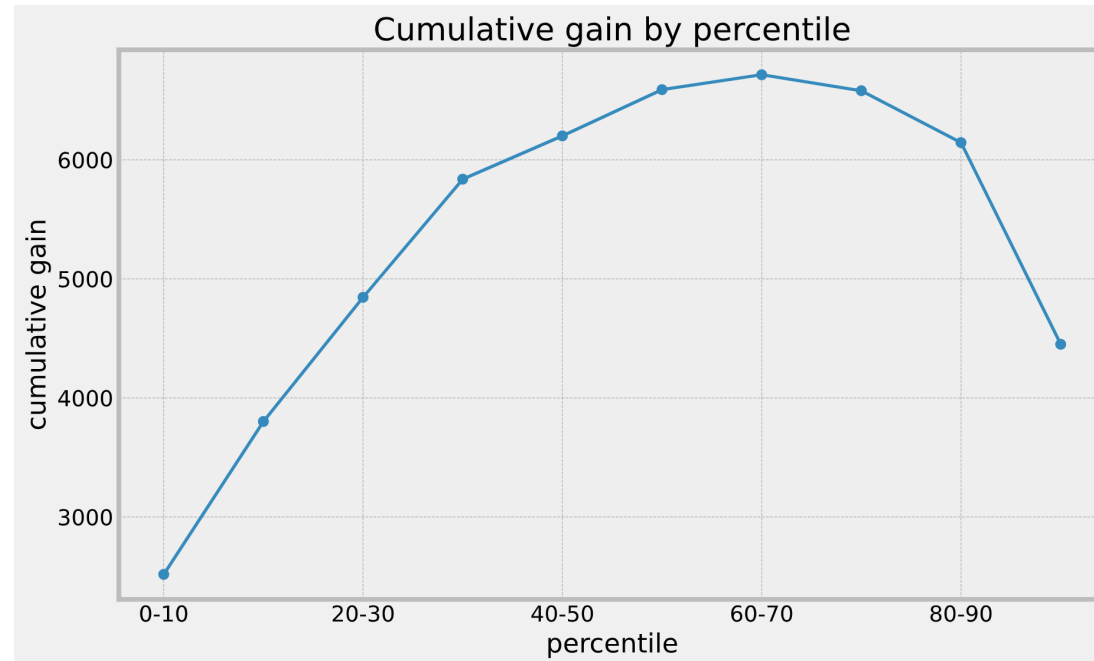
Predict uplift for both treated and control observations and compute the average prediction per decile (bins) in both groups. Then, the difference between those averages is taken for each decile.

$$\left( \frac{Y^T}{N^T} - \frac{Y^C}{N^C} \right) (N^T + N^C)$$

- $Y^T / Y^C$ : sum of the treated / control individual outcomes in the bin.
- $N^T / N^C$ : number of treated / control observations in the bin.

# Uplift Evaluation: Cumulative gain chart

```
(x["uplift"] * (x["n_treatment"] + x["n_control"])).cumsum()
```



- From this plot we see if the treatment has a global positive or negative effect and if they can expect a better gain by targeting part of the population.
- We can thus choose the decile that maximizes the gain as the limit of the population to be targeted.

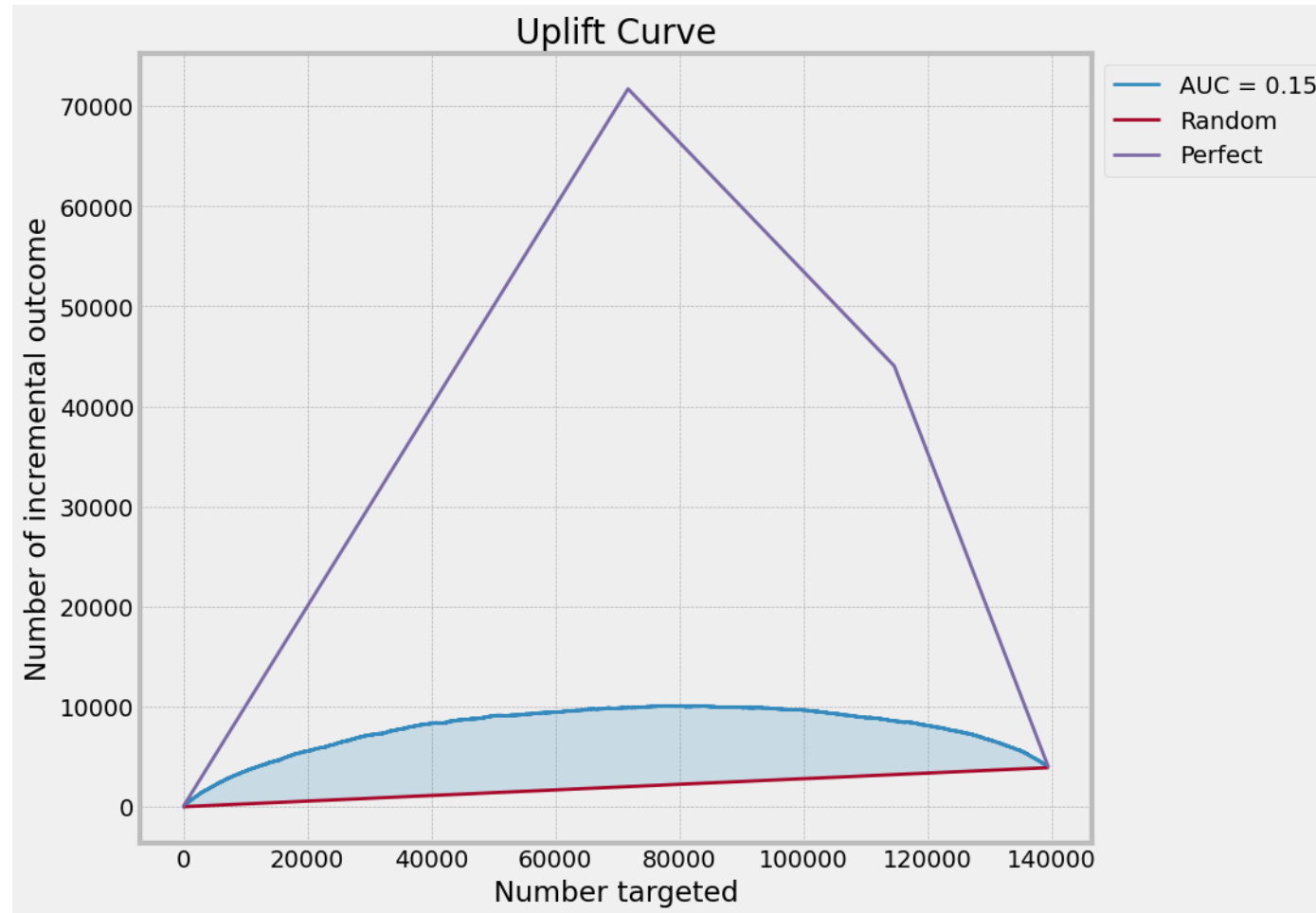
# Uplift Metrics: Uplift Curve

*We can generalize the cumulative gain chart for each observation of the test set:*

$$f(t) = \left( \frac{Y_t^T}{N_t^T} - \frac{Y_t^C}{N_t^C} \right) (N_t^T + N_t^C)$$

*where the  $t$  subscript indicates that the quantity is calculated for the first  $t$  observations, sorted by inferred uplift value.*

# Uplift Metrics: Uplift Curve & AUC

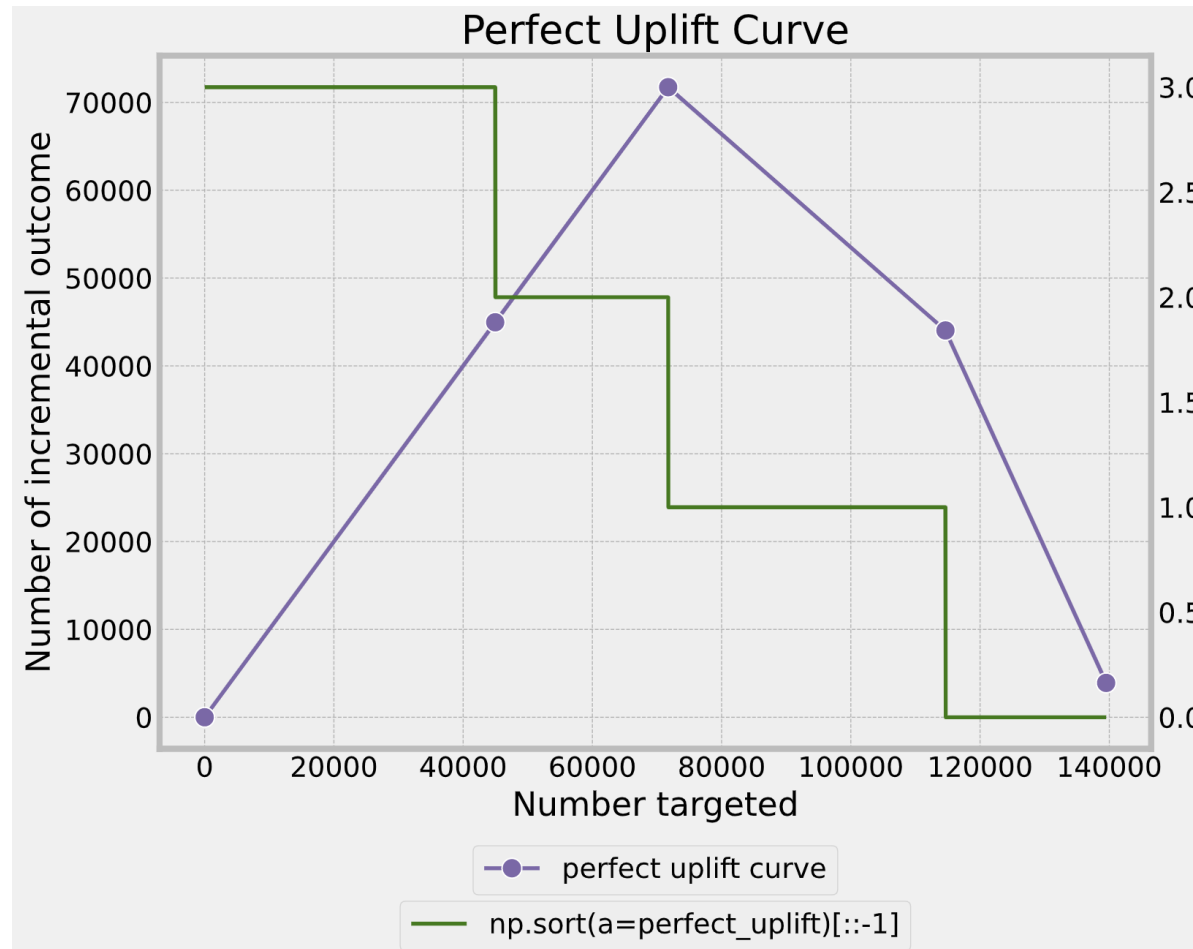


Plot function `plot_uplift_curve` from `scikit-uplift`

# Perfect Uplift Curve

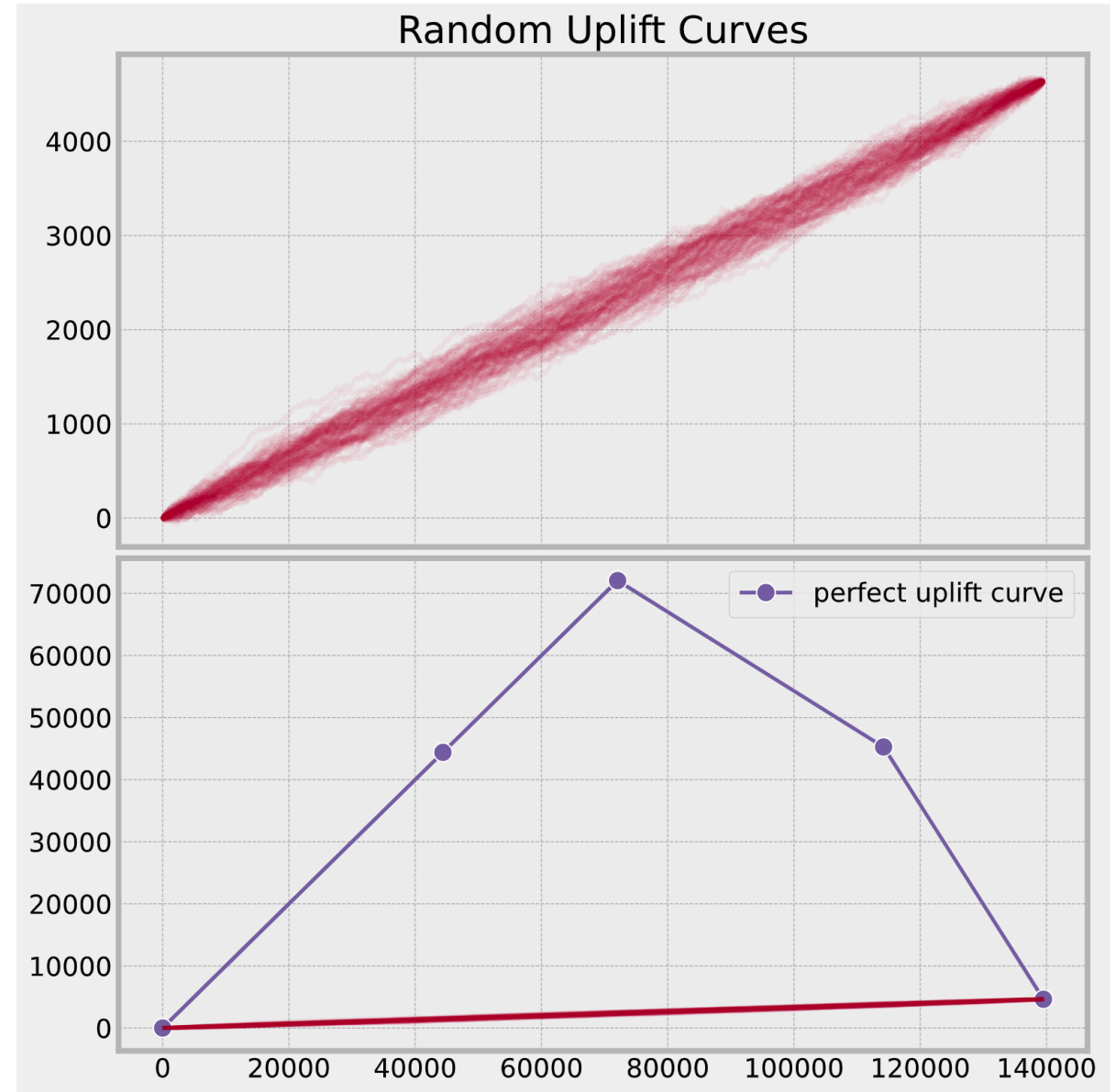
```
from sklift.metrics import uplift_curve
```

```
a, b = uplift_curve(y_true=y_true, uplift=perfect_uplift, treatment=treatment)
```



# Random Uplift Curves

```
np.random.uniform(  
    low=-1,  
    high=1,  
    size=(n, n_samples),  
)
```



# Demo

## Notebook Link

See <https://juanitorduz.github.io/uplift/>

## References:

- Diemert, Eustache, et.al. (2020) *"A Large Scale Benchmark for Uplift Modeling"*
- Gutierrez, P., & Gérardy, J. Y. (2017). *"Causal Inference and Uplift Modelling: A Review of the Literature"*
- Karlsson, H. (2019) *"Uplift Modeling: Identifying Optimal Treatment Group Allocation and Whom to Contact to Maximize Return on Investment"*
- Sören, R, et.al. (2019) *"Meta-learners for Estimating Heterogeneous Treatment Effects using Machine Learning"*



# Thank you!

More Info: [juanitorduz.github.io](https://juanitorduz.github.io)

