Customer Price Sensitivities in Competitive Automobile Insurance Markets

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Motivation

- Traditional insurance pricing only from costs to increase profits
- In reality, also demand effects that may indirectly decrease profits
- Confounding in assigned premium and a customer's response:

$$\text{Risk} \rightarrow \text{Premium} \rightarrow \text{Churn}$$

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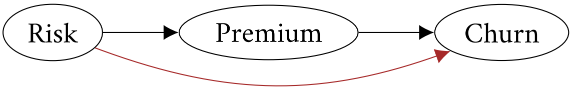

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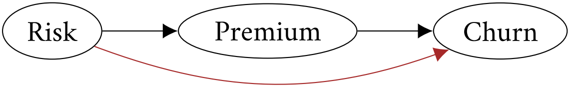


- Moreover, premia are not offered at random in practice

  → *So risk characteristics will be insufficiently balanced*
- Causal inference solution by Guelman and Guillén (2014):
  (i) *Discretize percentage premium changes*
  (ii) *Impute counterfactual responses with propensity score matching*
  (iii) *Optimize next period's profit given predicted responses*

Relevant previous studies

- Causal inference framework:
  - (i) *Discrete treatments*
    (Rosenbaum and Rubin, 1983; Rubin, 1997; Morgan and Winship, 2007; Guo and Fraser, 2009; Rosenbaum, 2010; McCaffrey et al., 2013; Guelman and Guillén, 2014; Wager and Athey, 2018)
  - (ii) *Continuous treatments*
    (Hirano and Imbens, 2004; Imai and Van Dyk, 2004; Fryges and Wagner, 2008; Guardabascio and Ventura, 2014; Zhu et al., 2015; Kreif et al., 2015; Zhao et al., 2018)
- Applications of continuous treatment framework sparse in non-life insurance

Customer price sensitivity

- Let random variable $Y_i(t) \in \{0, 1\}$ denote policy i's churning response to any potential rate change, or treatment, $t \in \mathcal{T}$
- Actually assigned treatment given by T_i with risk characteristics X_i
- Causal inference relies on two assumptions:
  - (i) *Actual rate changes depend only on the observed risk characteristics (weak unconfoundedness):* $Y_i(t) \perp T_i | X_i \quad \forall t \in \mathcal{T}$
  - (ii) *Each customer has non-zero probability of receiving every rate change (common support):* $0 < \pi(t, X_i) := \mathbb{P}[T_i = t | X_i] < 1 \quad \forall t \in \mathcal{T}$
- Together this allows identification of average treatment effects without bias by controlling for confounders (strong ignorability)

Discrete treatment categories

- Discretize observed treatments T_i in T categories $\{t_1, \ldots, t_T\}$
- Match customers based on similarity:
  (i) *Challenging or even impossible with many risk characteristics*
  (ii) *Propensity score* $\pi(t_s, X_i)$ *one-dimensional alternative, sufficient due to balancing property:* $T_i \perp X_i | \pi(t_s, X_i) \quad \forall s \in \{1, \ldots, T\}$
  (iii) *If strong ignorability holds conditional on* X_i *then also conditional on* π
- Propensity score to explain treatments T_i as accurately as possible
  → *XGBoost of Chen and Guestrin (2016) is appropriate for this* *Details*
- Impute counterfactual responses from propensity score matches
  → *Multiple imputation to (partially) include response uncertainty* *Details*
- Form global response model from both observed and imputed data

Continuous treatment doses

- Continuum of potential treatment doses $\mathcal{T} = [\underline{T}, \overline{T}]$
- Balancing and strong ignorability property still valid
- Traditional global response model only conditional on $\pi(T_i, X_i)$:
  (i) $$\mathbb{E}[Y_i(T_i)|\pi(T_i, X_i)] = \alpha_0 + \alpha_1\pi(T_i, X_i) + \alpha_2\pi(T_i, X_i)^2 + \alpha_3 T_i + \alpha_4 T_i^2 + \alpha_5\pi(T_i, X_i) T_i$$
  (ii) $$\widehat{\mathbb{E}[Y(t)]} = \frac{1}{N}\sum_{i=1}^{N} \left(\hat{\alpha}_0 + \hat{\alpha}_1\hat{\pi}(t, X_i) + \hat{\alpha}_2\hat{\pi}(t, X_i)^2 + \hat{\alpha}_3 t + \hat{\alpha}_4 t^2 + \hat{\alpha}_5\hat{\pi}(t, X_i) t\right)$$
- No direct causal interpretation of global response model
  - $\rightarrow$ *So can use XGBoost for this as well*
  - $\rightarrow$ *Can still use it to predict individual potential responses*

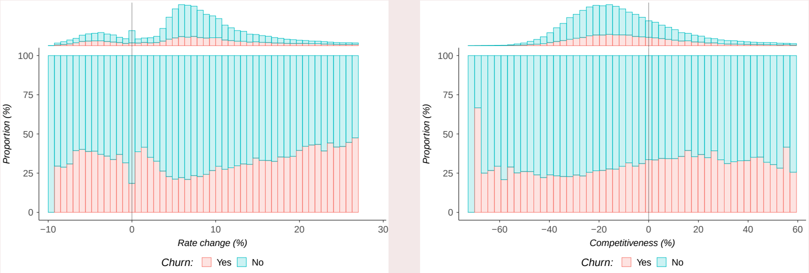
Dutch automobile insurance portfolio

- Individual policy renewals from 2017-2019:
  (i) $71{,}522$ *policies with* $20{,}649$ (28.87%) *lapses*
  (ii) *Rate change quintile intervals* $[-9.28\%, 1.53\%]$, $(1.53\%, 6.06\%]$, $(6.06\%, 8.58\%]$, $(8.58\%, 12.58\%]$ *and* $(12.58\%, 27.01\%]$
- Premia offered by the six largest competitors:
  (i) *Competitiveness* $(B - A)/A$ *of each renewal offer before any rate changes* (A) *relative to current cheapest competing offer* (B)
  (ii) *Underpricedness of renewal offers compared to cheapest and second-cheapest competitor*

Observed churn proportions

- Stable, slowly increasing churn ratios
- Relatively large inflection at small rate changes
  - → *Indication of let sleeping dogs lie effect*

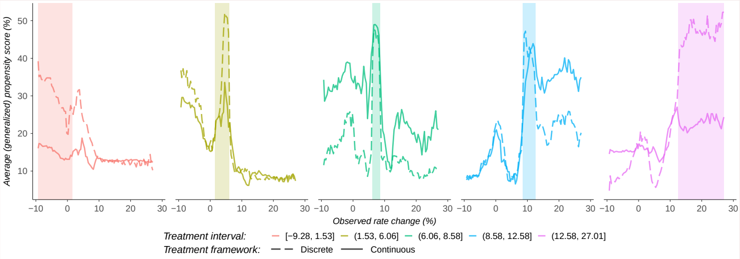
Churn proportions, rate changes (left) - competitiveness (right)



Propensity score matching

- Increase in balance of each risk factor, up to 95%
- Discrete approach improves balance considerably more:
  - (i) *Optimizes the rate change interval assignments directly*
  - (ii) *Only has to distinguish between five categories*
- Common support and hence strong ignorability hold

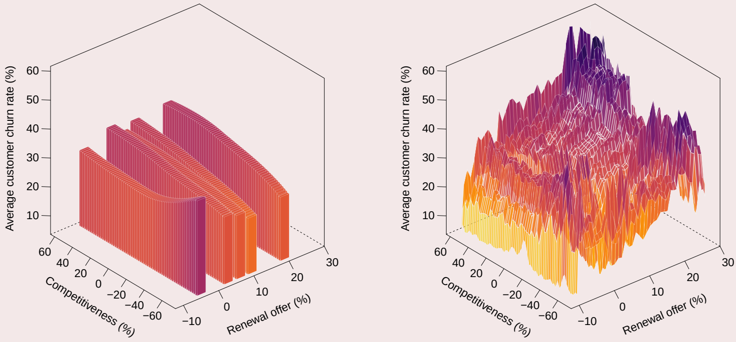
Average propensity scores



Customer price sensitivities

- Intuition:
  - (i) *More worthwhile to switch at higher or very small rate changes*
  - (ii) *Comparison of insurers more likely for very competitive policies*

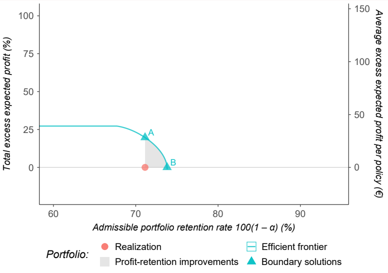
Average customer churn, discrete (left) - continuous (right)

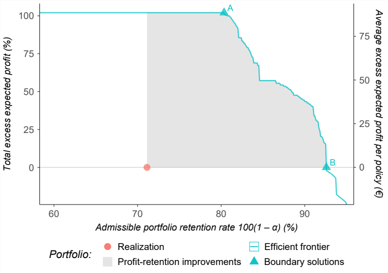


Efficient frontier

- Constrained optimization of next year's expected profit: Details
  - (i) *Trade-off between customer churn and profit potential*
  - (ii) *Only small improvement due to multiple imputation*
  - (iii) *Substantially more profit in continuous approach due to XGBoost and ability to distinguish between rate changes in each interval*

Efficient frontier, discrete (left) - continuous (right)





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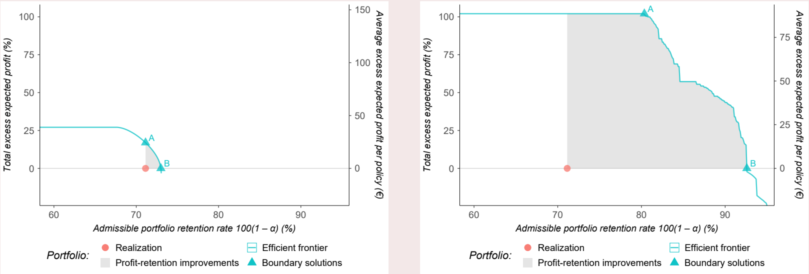
Efficient frontier, discrete one imputation (left) - continuous (right)



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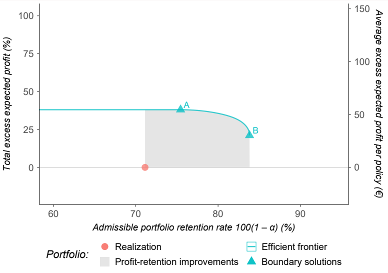
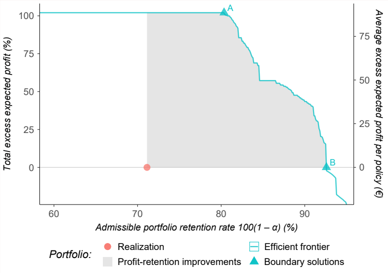
Efficient frontier, discrete XGBoost (left) - continuous (right)





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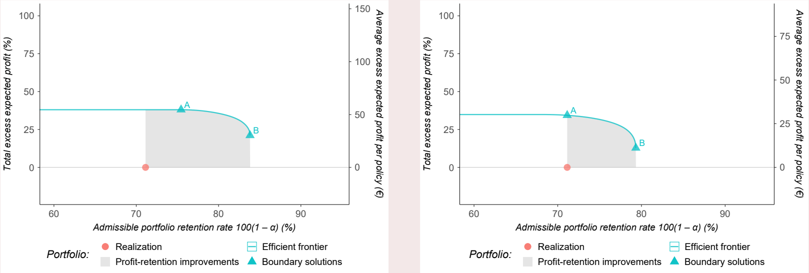
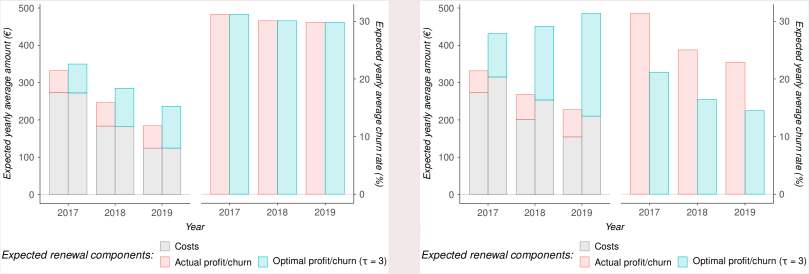
Efficient frontier, discrete XGBoost (left) - continuous restricted (right)



Multi-period renewal optimization

- Constrained optimization of expected profit over τ periods: Details
  - (i) *Slightly lower rate changes in first period due to temporal feedback*
  - (ii) *Substantially more profit possible, especially in continuous approach*

Expected yearly profit and churn, discrete (left) - continuous (right)



Conclusion

- Shift from cost-based pricing to demand-based pricing
- Causal inference approach required to adjust for confounding
- Application to automobile insurance shows:
  (i) *Policy's competitiveness crucial for price sensitivity*
  (ii) *Substantially more profit can be gained than realized, also already with less churn and in particular using continuous approach*
  (iii) *Temporal feedback of previous rate changes on future demand enabled through competitiveness*

Future research

- Introduce risk characteristics in matching procedure
- Primary focus on logistic GLMs and XGBoost:
  (i) *Compare to alternative machine learning methods, such as (causal) random forests, (deep) neural networks or support vector machines*
  (ii) *Consider ensemble of various (machine learning) models*

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XGBoost and multiple imputation

- Gradient Boosting Models for propensity score: Return
  - (i) *Combines many weak learners to learn from errors of previous learners*
  - (ii) *Flexible non-linear effects of risk factors*
  - (iii) *Identification of complex interactions in tree-learning algorithm*
  - (iv) *Built-in variable selection procedure*
- XGBoost of Chen and Guestrin (2016) more flexible and faster
- Multiple imputation to (partially) include response uncertainty:
  - (i) *Randomly sample M counterfactual responses from I closest matches*
  - (ii) *Combine global response estimates $\delta_m = (\beta_m, \gamma_m)$:*
    $\bar{\delta} = \frac{1}{M} \sum_{m=1}^{M} \hat{\delta}_m$ *and* $\text{Var}(\bar{\delta}) = \bar{W} + \left(1 + \frac{1}{M}\right) B$
  - (iii) *Within-imputation, or parameter, uncertainty:*
    $\bar{W} = \frac{1}{M} \sum_{m=1}^{M} \hat{W}_m$
  - (iv) *Between-imputation, or imputation, uncertainty:*
    $B = \frac{1}{M-1} \sum_{m=1}^{M} \left(\hat{\delta}_m - \bar{\delta}\right)' \left(\hat{\delta}_m - \bar{\delta}\right)$

Constrained renewal optimization

- Constrained optimization of next year's expected profit: Return

$$\max_{\{t_i\}_{i=1}^{N} \in \mathcal{T}^N} \left\{ \sum_{i=1}^{N} \left(1 - \hat{Y}_i(t_i)\right) \left(\texttt{Premium}_i - \texttt{Costs}_i\right) \right\} \text{ s.t. } \frac{1}{N} \sum_{i=1}^{N} \hat{Y}_i(t_i) \leq \alpha$$

- Constrained optimization of expected profit over τ periods: Return

$$\max_{\{t_{i,j}\}_{i=1,j=1}^{N,\tau} \in \mathcal{T}^{N\tau}} \left\{ \sum_{i=1}^{N} \sum_{j=1}^{\tau} \left(\prod_{h=1}^{j} \left[1 - \hat{Y}_i(t_{i,1}, \ldots, t_{i,h})\right] \right) \left(\texttt{Premium}_{i,j} - \texttt{Costs}_{i,j}\right) \right\}$$

$$\text{s.t. } \frac{1}{N} \sum_{i=1}^{N} \hat{Y}_i(t_{i,1}, \ldots, t_{i,j}) \leq \alpha_j \quad \text{for} \quad j = 1, \ldots, \tau$$

→ *Overall churn rate limited to average churn rate expected for actual renewal offers, or* $\alpha_j = \frac{1}{N} \sum_{i=1}^{N} \hat{Y}_i(T_{i,1}, \ldots, T_{i,j})$ *for* $j = 1, \ldots, \tau$