Demand and Price Elasticity Modelling

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The views and opinions expressed in this presentation are independent of employer of the presenter or the Actuarial Profession

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Agenda

• Introduction
• Current approaches used in the market
• Common pitfalls and considerations of the GLM approach
• Decision tree type approach
• Summary and Q & A
Introduction

• The idea initiated by a CAS call for monograph in early 2015
• Purpose of this research
  – Survey of different methods of conversion and elasticity models
  – Research on new methods
  – Not limited to insurance industry

What is demand model

• Demand is defined as the number of sales divided by number of quotes/renewal invites
• Conventionally called ‘conversion model’ for new business and ‘retention model’ for renewal business
• Premium might or might not be a factor in the model
What is price elasticity model

• Price elasticity measures the change in demand divided by the change in premium, mathematically,

\[ e = - \lim_{\Delta p \to 0} \frac{\Delta d/d_0}{\Delta p/p_0} = - \frac{\partial d p_0}{\partial p d_0} \]

• Conventionally add the minus sign to make it a positive number

Demand and price elasticity models are important components in pricing analysis

• Price elasticity model is particularly important in price optimisation
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Current approaches used in the market

- One-way and two-way analysis
  - Easy to calculate
  - Ignore correlation in the explanatory variables
  - Not suitable for complicated analysis

- Generalised linear model (GLM)

- Generalised non-linear model
  - Guarantee that elasticity is always positive
  - Computationally intensive

- Neural networks
  - Understand the results is a challenge
The GLM approach: price elasticity derived from the demand model

Model setting

- Logit link function \( \Phi = g^{-1}(\eta) = \frac{1}{1+e^{\eta}} \)
- Binomial distribution error structure
- Linear component \( \eta = X\beta_d + \Delta p X\beta_e \)

It is important to have randomised price tests

- GLM explains the difference in demand by normal rating factors (age, area etc) and premium
- If the price test correlated with one rating factors, GLM will get confused whether it is the rating factor or the price difference cause the difference in demand

<table>
<thead>
<tr>
<th>Base scenario</th>
<th>Random price test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>Demand</td>
</tr>
<tr>
<td>Young</td>
<td>10%</td>
</tr>
<tr>
<td>Old</td>
<td>20%</td>
</tr>
</tbody>
</table>

| Extreme scenario: Young always gets discount |
| Age | Demand - Champion | Demand – Challenge |
| Young | 20%       |
| Old | 20%       |
Price elasticity can only be observed for a group of risk

- Reconciliation of price elasticity at individual level is always an approximation
Non-linearity or break point are expected in demand model

- Demand depends on the market premium and own premium
- Even simple pricing action can give non-linearity effect in demand
Non-linearity or break point are expected in demand model

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Extrapolate of model is common but much more dangerous

- Where there is limited number of sales, the model largely depend on extrapolation of neighbouring segments

Demand in high mileage relying on the mid-range mileage. It can't tell the difference in elasticity.
Derived elasticity has high uncertainty

\[
\text{Elas} = \frac{(15\%-10\%)/10\%}{5\%} = 10
\]

If SD of conv is 10% of conv, SD of Elas is
\[(1\%^2+1.5\%^2)^0.5/10\%/5\% = 3.6, 36\% \text{ of Elas}
\]

- Uncertainty of price elasticity is compounded by uncertainty of demand
- And dominated by the high uncertain point

Model reconciliation

- One way chart

- How to calculate actual price elasticity? Is it possible?
- How to calculate modelled price elasticity?
- How to make them consistent and comparable?
Model reconciliation

- Lift curve is even more a challenge

- How to calculate model price elasticity for individual policy? What is the price point?
- Calculate model and actual price elasticity in bands is same as one way chart

**Graph:**
- X-axis: Band
- Y-axis: Demand
- Line: Model demand
- Points: Actual demand

Understand the impact of model uncertainty

- Risk cost / expense model
- Conversion model
- Retention model
- Expected profit per quote
- Optimal premium

- This uncertainty is compounded with winner’s curse
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Decision tree
Idea of tree based approach

- Decision tree approach provides a top-down approach that focuses on segments

```
Champion | Challenge
---|---

Elasticity = 5

Elasticity = 3
```

- Split at a place that differentiates the price elasticity most

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Champion | Challenge
---|---

Elasticity = 7

Elasticity = 7
```

The idea of tree based approach

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Champion | Challenge
---|---

Elasticity = 4

Elasticity = 2
```

```
Champion | Challenge
---|---

Elasticity = 7
```

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GLM could be applied to adjust the difference in mixture

• Algorithm
  – Step 1: For each possible split, build a GLM on demand including price test as an explanatory variable. Record the impact of price test.
  – Step 2: Find the split that has the maximum impact of price test
  – Step 3: If stop criteria is not met, go to Step 1. Otherwise, stop.
  – Step 4: Build GLM in each leaf of the tree

Literatures

• Using Generalised Linear Model to Build Dynamic Pricing Systems, Karl P. Murphy, Michael J. Brockman, and Peter K. W. Lee
• Beyond the Cost Model: Understanding Price Elasticity and Its Applications, Serhat Guven, FCAS, MAAA, and Michael McPhail, FCAS, MAAA
• Real-World Uplift Modelling with Significance-Based Uplift Trees, Nicholas J. Radcliffe
• An Application of Genetic Algorithms to Uplift Modelling, David P. Hofmeyr
• Optimal personalized treatment rules for marketing interventions: A review of methods, a new proposal, and an insurance case study, Leo Guelman, Montserrat Guillén and Ana M. Pérez-Marín
• Demand Modelling Working Party report, James Tanser, John Light, Sophia Mealy and Owen Morris
Summary

- Demand and price elasticity models could be spuriously accurate
- Great attention is needed in model check and understanding uncertainty
- Decision tree type model is a top-down approach that focus on segments, that potentially reduce spurious accuracy

Questions

Expressions of individual views by members of the Institute and Faculty of Actuaries and its staff are encouraged.

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