Picking Particular Pure Premium Model Presumptions

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NATIONAL ASSOCIATION OF INSURANCE COMMISSIONERS

PURPOSE OF THE PROJECT

- There are multiple distributional assumptions that could be made for modeling pure premium
  - Tweedie ($1 < p < 2$)
  - Poisson
  - Quasipoisson
- There are not many papers considering Poisson distribution for building pure premium models
- Topic introduced at 2022 RPM Seminar
  - Alternative to the Tweedie in Pure Premium GLM – RPM Seminar 2022 by David R. Clark

Agenda

1. Introduction to the distributions
2. Inverse Transformation Sampling
3. Side-by-side output review
4. Review of Model Metrics
5. Model Run Time
6. Conclusions

1. Introduction

- $Pure\ Premium = \frac{\$\ Loss}{Exposures}$
- GLM Monograph:
  - Severity: "…two commonly used distributions are the gamma and inverse Gaussian distributions."
  - Frequency: "…the most commonly used distribution is the Poisson distribution. Another available choice is the negative binomial distribution."
  - A distribution for Pure Premium: the Tweedie Distribution
    - Most policies have a pure premium of $0 for a given policy year
    - When there are losses, the distribution tends to be highly skewed

Tweedie Distribution

Definition : Versatile family of probability distributions.

$$V(\mu) = \mu^p$$

Special cases of power parameter:

- p=0 : Gaussian
- p=1 : Poisson
- 1<p<2 : Compound poisson-gamma
- p=2 : Gamma
- p>2: Inverse Gaussian distribution

Table 1. The Exponential Family Variance Functions

Distribution	Variance Function [$V(\mu)$]	Variance [$\phi V(\mu)$]
normal	1	ϕ
Poisson	μ	$\phi\mu$
gamma	μ^2	$\phi\mu^2$
inverse Gaussian	μ^3	$\phi\mu^3$
negative binomial[2]	$\mu(1+\kappa\mu)$	$\phi\mu(1+\kappa\mu)$
binomial	$\mu(1-\mu)$	$\phi\mu(1-\mu)$
Tweedie	μ^p	$\phi\mu^p$

Variance Per Observation

	Tweedie (1 < p < 2)	Poisson	Quasi-Poisson
ϕ	ϕ	1	ϕ
$V(\mu_i)$	μ^p	μ	μ

$$Var[y_i] = \frac{\phi V(\mu_i)}{\omega_i}$$

- Example:
  - Tweedie (p = 1.5), ϕ = 2, Log-link model
  - Linear predictor = 4.605
  - Earned Car Years = 1
  - μ = exp(4.605) = 100
  - Var(μ) = 2 * (100^1.5) / 1 = 2,000

- Example:
  - Poisson, Log-link model
  - Linear predictor = 4.605
  - Earned Car Years = 1
  - μ = exp(4.605) = 100
  - Var(μ) = 1 * (100) / 1 = 100

Distributions Considered

- Tweedie with a p power parameter between 1 and 2
  - Recommended by CAS GLM Monograph
  - Most commonly used distribution assumption
  - Check a selected value (1.5) vs. the optimized value
- Poisson
  - Reportedly produces similar predictions to Tweedie ($1 < p < 2$)
  - Reportedly faster model run times
- Quasipoisson
  - More flexible on variance assumption
  - Potentially faster than Tweedie ($1 < p < 2$)

Datasets Used

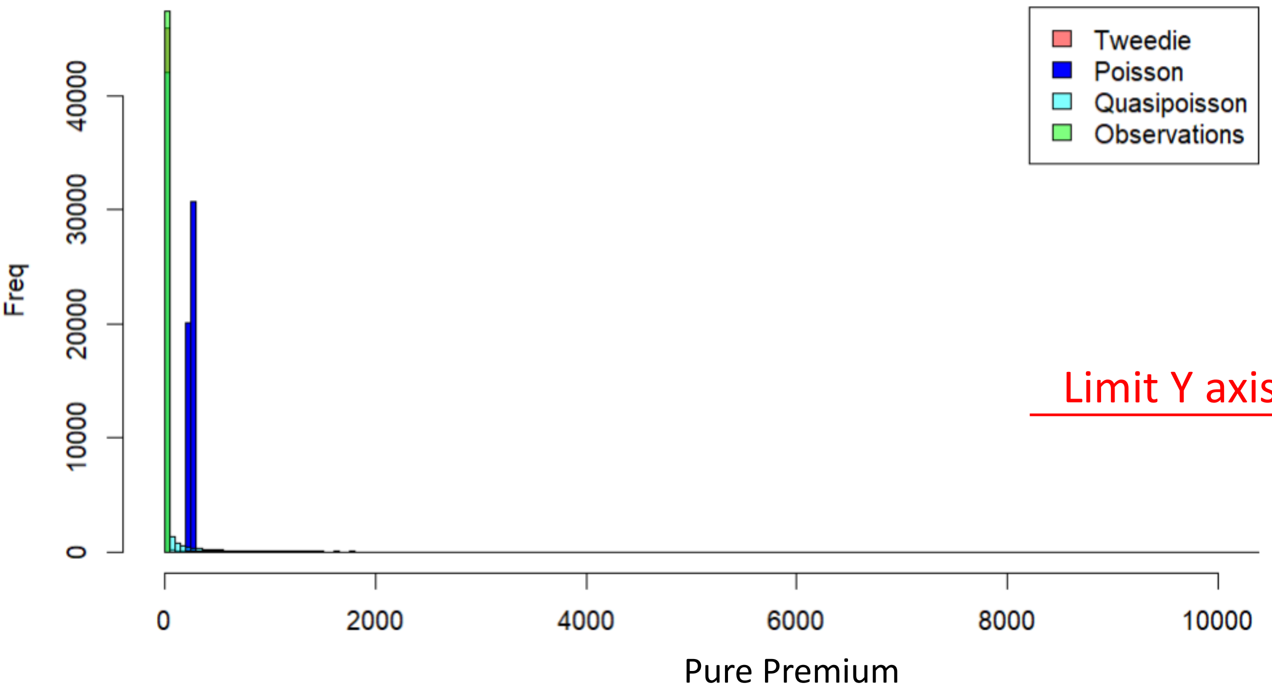
Library : CASdatasets compiled for the book "Computational Actuarial Science with R“ by Arthur Charpentier

	Ausprivaut00405	Brvehins2	pricingGame
Country	Australia	Brazil	France
Year	2004-2005	2011	2015
Line of Business	Auto	Auto	Auto
Row Count	67,856	1,965,355	100,000

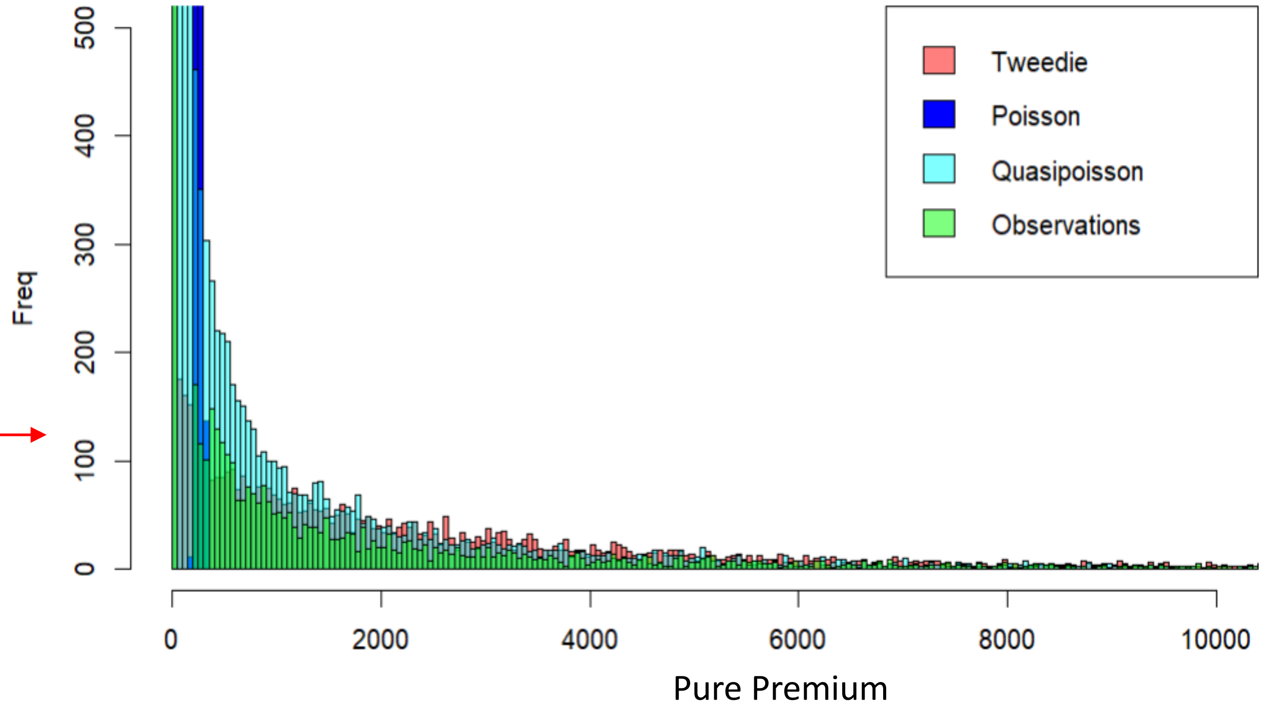
2. INVERSE TRANSFORMATION SAMPLING

- Determine parameters based on the empirical data
  - Mean
  - Dispersion Parameter
  - p power parameter
- Run thousands of simulations
  - rpois()
  - rtweedie()
  - rqpois()
- Check distribution of simulations vs. distribution of observations

INVERSE TRANSFORMATION SAMPLING - AUSPRIVAUTO



Limit Y axis



Tweedie Range = 0-26,051

Poisson Range = 186-338

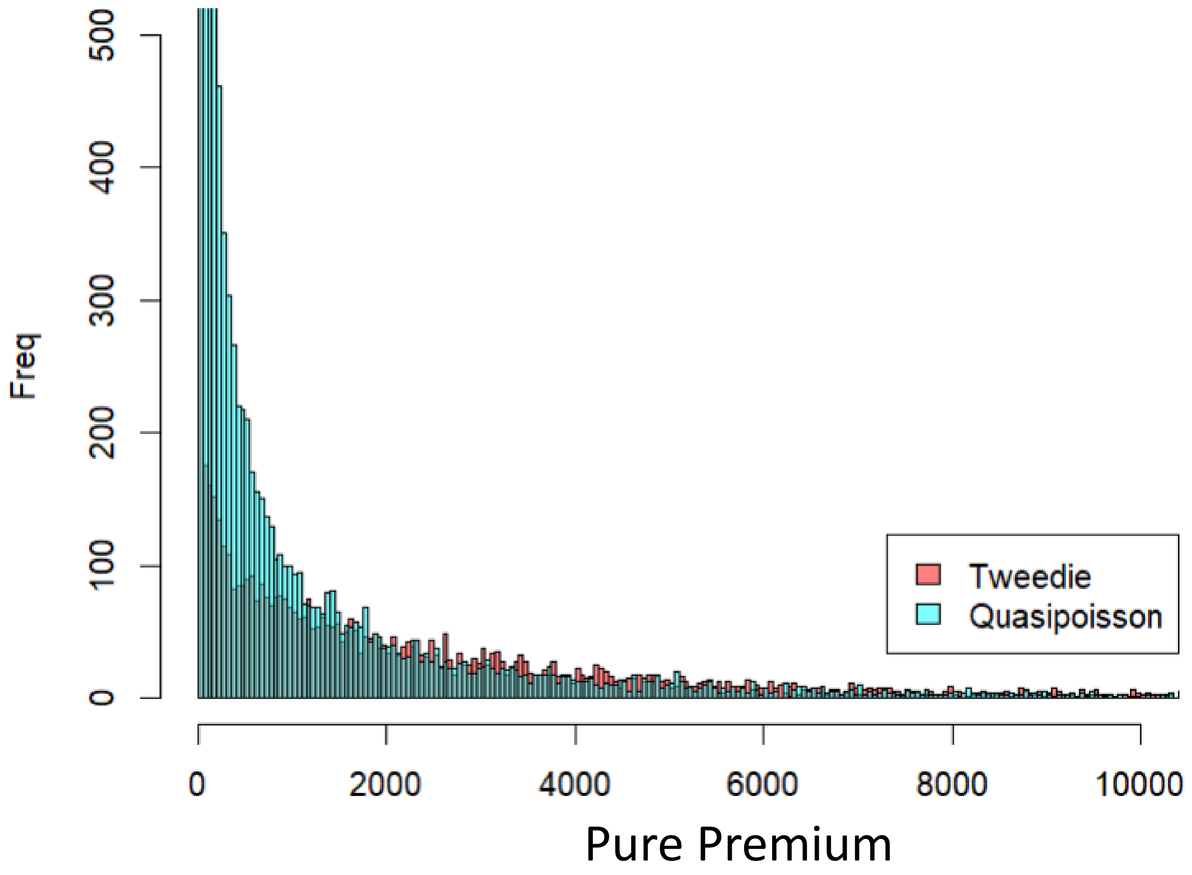
Quasipoisson Range = 0-29,621

Observations Range = 0-51,005

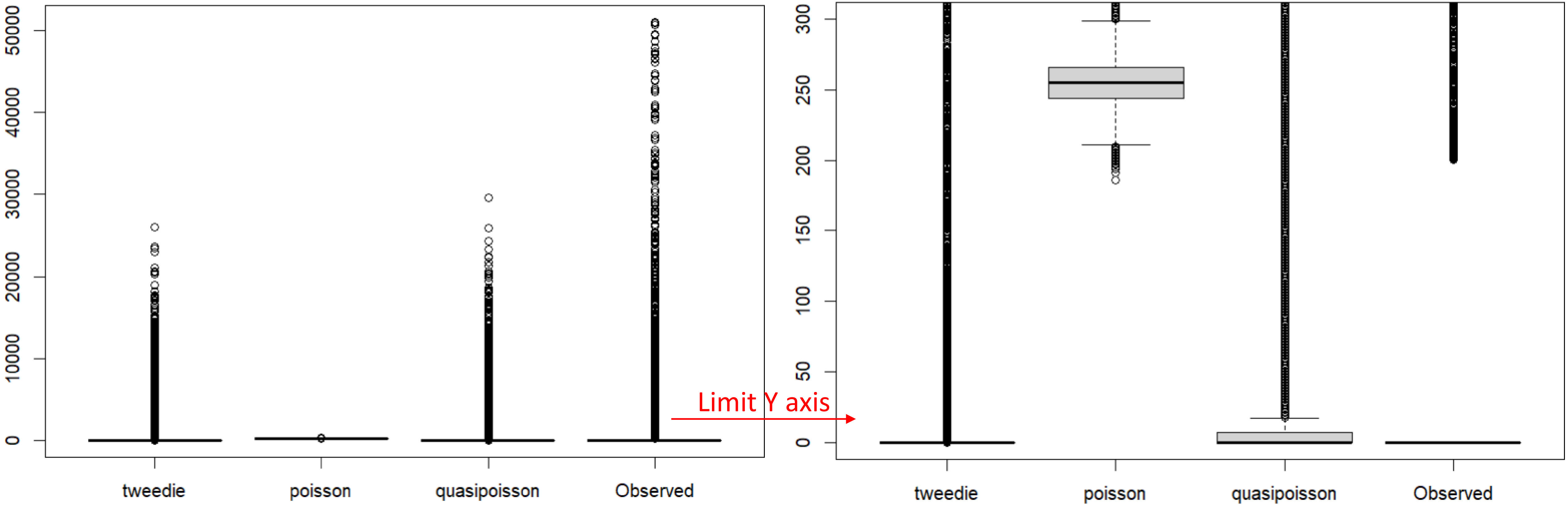
INVERSE TRANSFORMATION SAMPLING - AUSPRIVAUTO

- Samples = 51,020
- Lambda = mean(Pure premium of the data)
- Tweedie power = 1.58
- Dispersion parameter(Tweedie)= 223
- Dispersion parameter(Quasipoisson)= 5,432

Tweedie power absorbs most of the dispersion



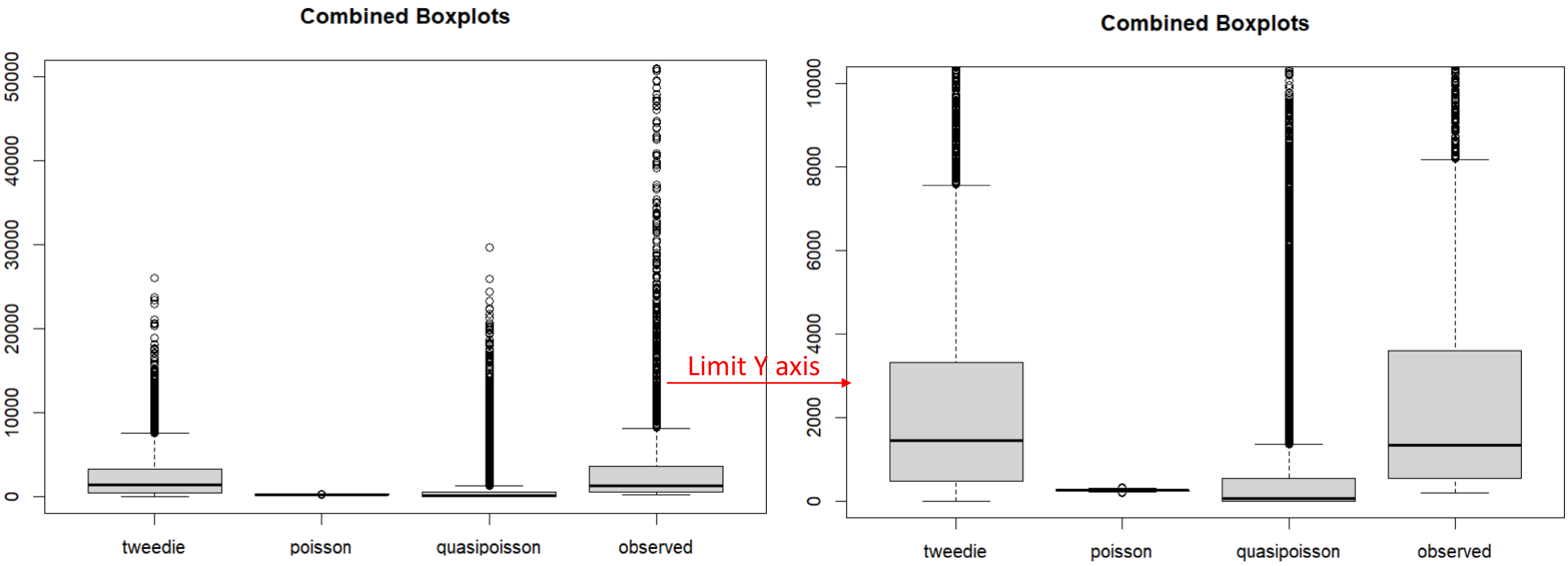
INVERSE TRANSFORMATION SAMPLING - AUSPRIVAUTO



# of non-Zero rows tweedie = 5,425	89.3% is 0
# of non-Zero rows poisson = 51,020	0% is 0
# of non-Zero rows quasipoisson = 17,009	66.6% is 0
# of non-Zero rows observed = 3,608	92.9% is 0

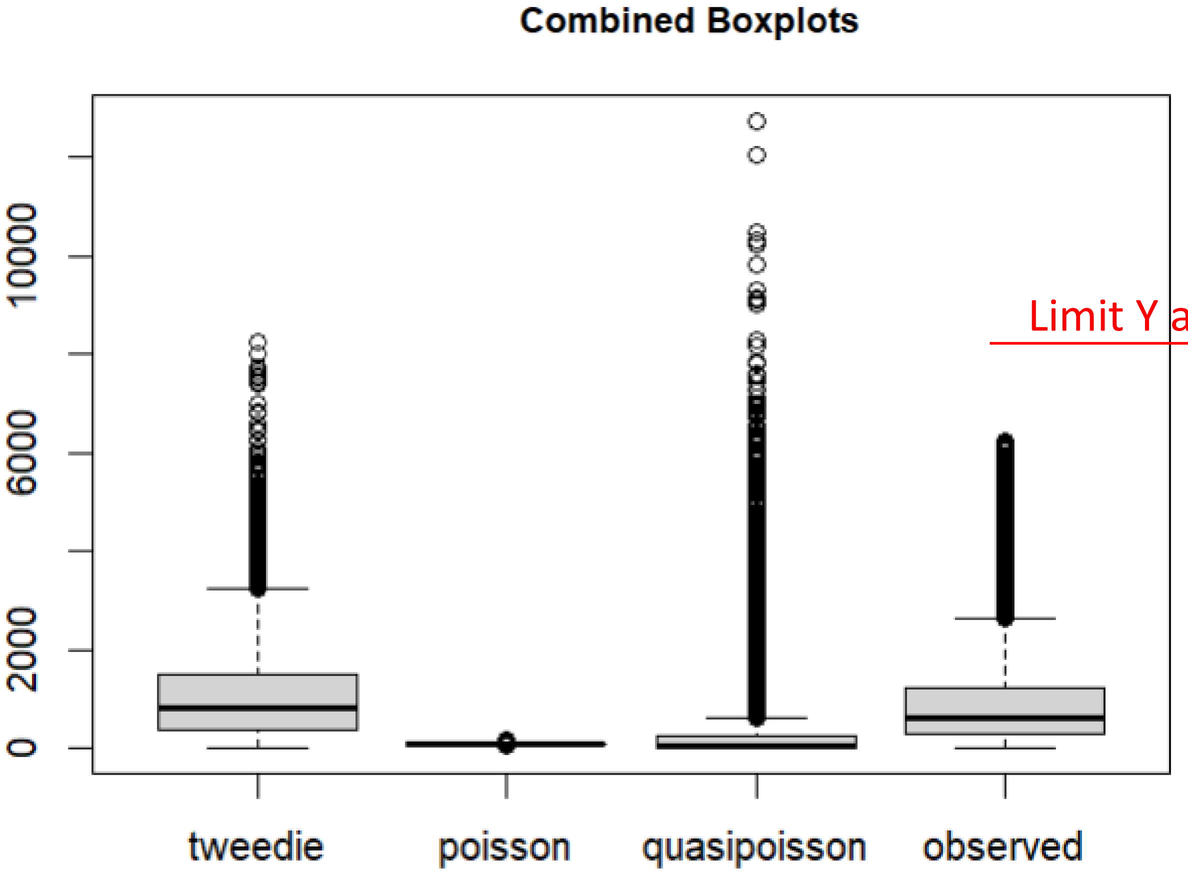
INVERSE TRANSFORMATION SAMPLING - AUSPRIVAUTO

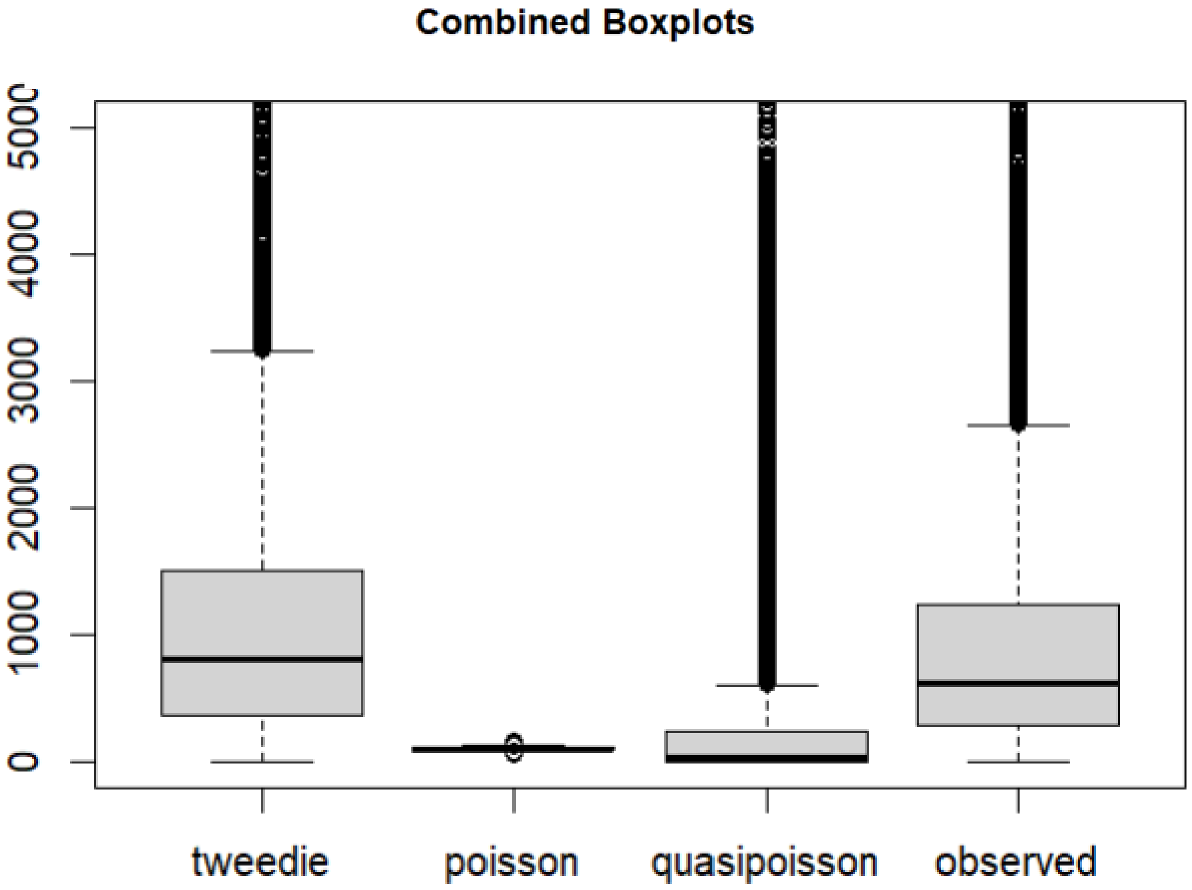
Non-Zero rows



INVERSE TRANSFORMATION SAMPLING – PRICING GAME

Non-Zero rows

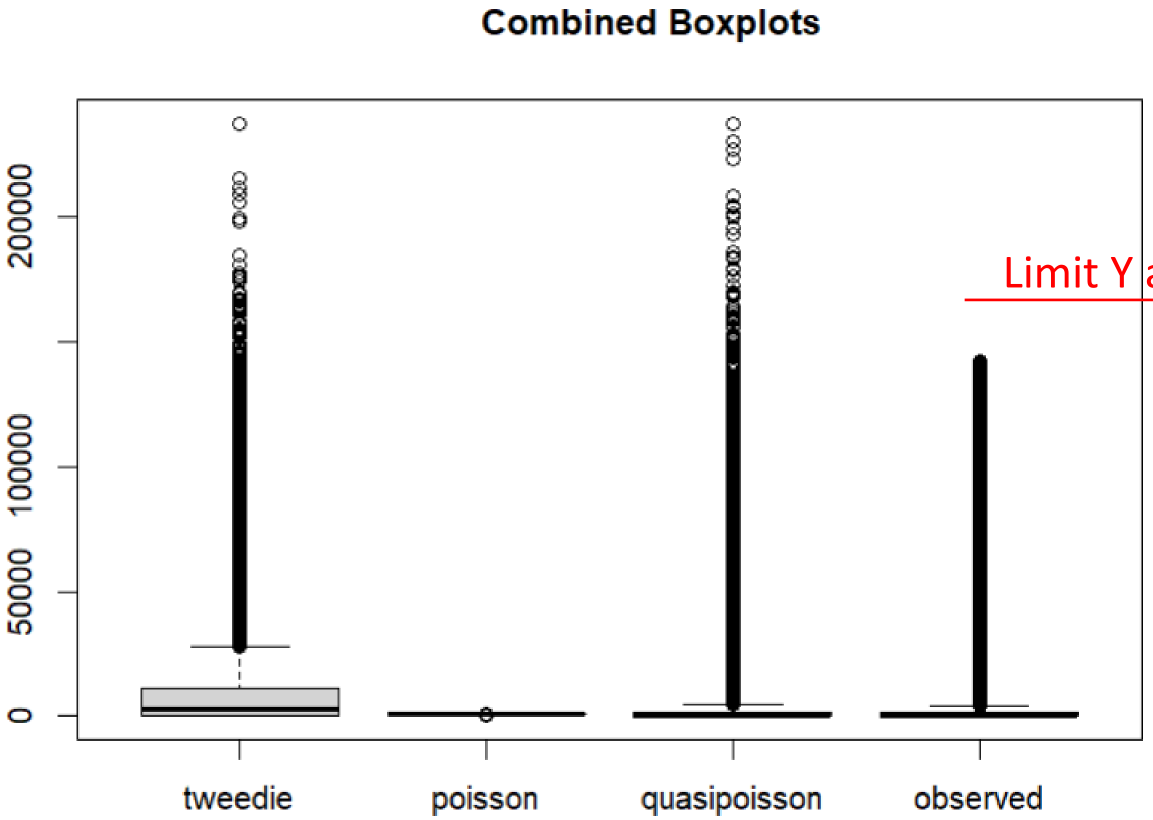




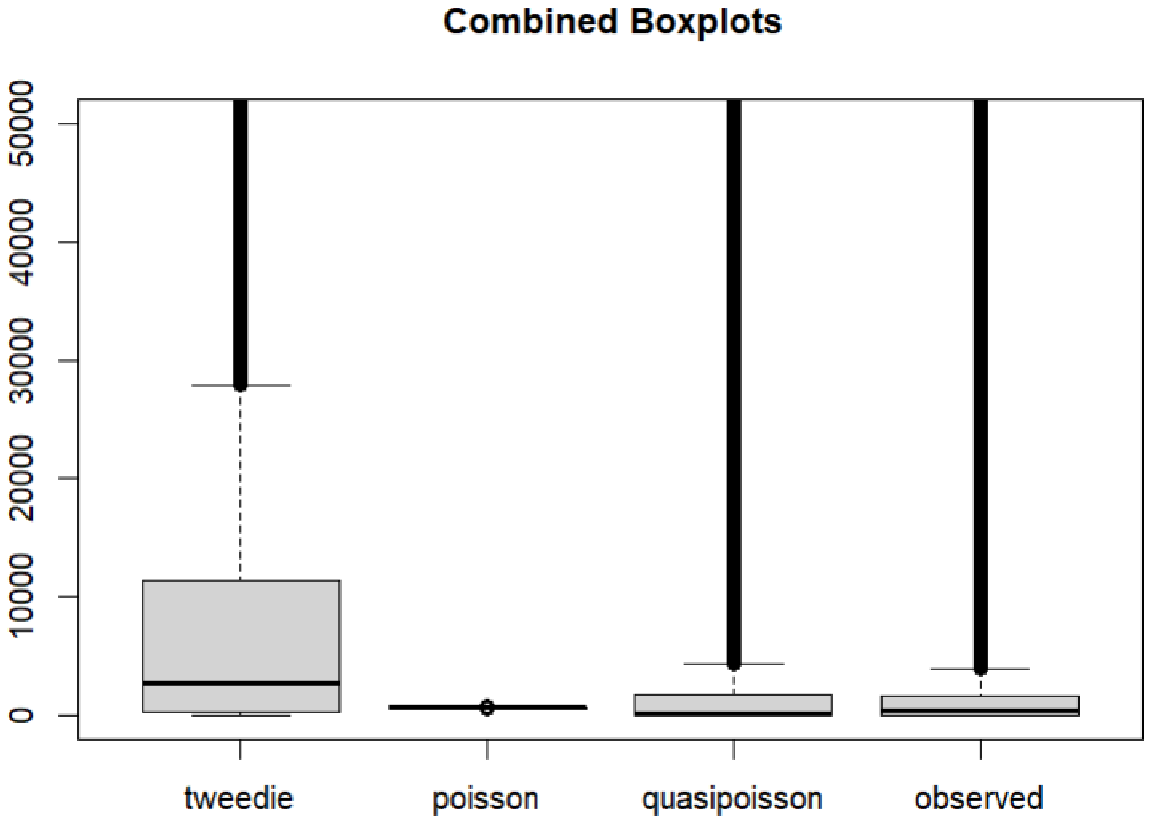
# of non-Zero rows tweedie = 7,958 90% is 0
# of non-Zero rows poisson = 79,920 0% is 0
# of non-Zero rows quasipoisson = 29,451 63.1% is 0
# of non-Zero rows observed = 8,788 89% is 0

INVERSE TRANSFORMATION SAMPLING - BRVEHINS

Non-Zero rows



Limit Y axis



# of Non-Zero rows tweedie = 73,632	93.1% is 0
# of Non-Zero rows poisson = 1,074,090	0% is 0
# of Non-Zero rows quasipoisson = 203,180	81.1% is 0
# of Non-Zero rows observed = 223,170	79.2% is 0

3. Side-by-Side Model Output

- Run the models on the same datasets using different assumptions:
  - Poisson
  - Tweedie (1.5 and Optimized)
  - Quasi-Poisson
  - Frequency and Severity separately
- Check coefficients and p-values
  - Equivalent coefficients means equivalent model predictions
  - Differing p-values may impact our final variable selection

Comparison of Model Coefficients/Significance Values

AUSPRIVAUTO

p<0.01%
0.01%<p<0.05%
0.05%<p<0.1%
0.1%<p

Variables/Levels	Poisson Coeff	P value	Tweedie Opt Coeff	P value	Tweedie 1.5 Coeff	P value	Tweedie 1 Coeff	P value	Quasipoisson Coeff	P value	Frequency Coeff	P value	Severity Coeff	P value	Combined Coeff
(Intercept)	5.32	0.00	5.32	0.00	5.32	0.00	5.32	0.00	5.32	0.00	-1.90	0.00	7.21	0.00	5.30
GenderMale	0.09	0.00	0.10	0.12	0.10	0.12	0.09	0.15	0.09	0.15	-0.04	0.28	0.13	0.01	0.10
relevel(DrivAge, ref = 2)old people	-0.37	0.00	-0.37	0.00	-0.37	0.00	-0.37	0.00	-0.37	0.00	-0.23	0.00	-0.15	0.07	-0.39
relevel(DrivAge, ref = 2)oldest people	-0.18	0.00	-0.20	0.09	-0.19	0.09	-0.18	0.14	-0.18	0.14	-0.21	0.00	0.00	0.98	-0.20
relevel(DrivAge, ref = 2)working people	-0.01	0.00	-0.02	0.79	-0.02	0.81	-0.01	0.92	-0.01	0.92	0.02	0.73	-0.04	0.61	-0.02
relevel(DrivAge, ref = 2)young people	0.05	0.00	0.03	0.71	0.04	0.69	0.05	0.59	0.05	0.59	0.07	0.13	-0.03	0.67	0.04
relevel(DrivAge, ref = 2)youngest people	0.42	0.00	0.40	0.00	0.40	0.00	0.42	0.00	0.42	0.00	0.25	0.00	0.14	0.14	0.38
relevel(VehAge, ref = 1)oldest cars	-0.04	0.00	-0.03	0.72	-0.03	0.70	-0.04	0.60	-0.04	0.60	-0.08	0.09	0.07	0.37	-0.01
relevel(VehAge, ref = 1)young cars	-0.06	0.00	-0.05	0.51	-0.05	0.51	-0.06	0.50	-0.06	0.50	0.10	0.03	-0.13	0.06	-0.03
relevel(VehAge, ref = 1)youngest cars	-0.06	0.00	-0.06	0.56	-0.06	0.56	-0.06	0.53	-0.06	0.53	0.06	0.24	-0.12	0.15	-0.06
relevel(VehBody, ref = 10)Bus	1.02	0.00	1.02	0.25	1.02	0.23	1.02	0.12	1.02	0.12	1.03	0.00	-0.03	0.96	1.00
relevel(VehBody, ref = 10)Convertible	-0.33	0.00	-0.25	0.79	-0.26	0.78	-0.33	0.73	-0.33	0.73	-0.93	0.20	0.63	0.57	-0.30
relevel(VehBody, ref = 10)Coupe	0.86	0.00	0.83	0.00	0.83	0.00	0.86	0.00	0.86	0.00	0.50	0.00	0.34	0.10	0.84
relevel(VehBody, ref = 10)Hardtop	0.22	0.00	0.22	0.24	0.22	0.24	0.22	0.23	0.22	0.23	0.06	0.60	0.17	0.30	0.22
relevel(VehBody, ref = 10)Hatchback	0.22	0.00	0.21	0.01	0.21	0.01	0.22	0.01	0.22	0.01	-0.07	0.11	0.29	0.00	0.22
relevel(VehBody, ref = 10)Minibus	0.25	0.00	0.21	0.50	0.21	0.48	0.25	0.38	0.25	0.38	-0.18	0.32	0.39	0.19	0.20
relevel(VehBody, ref = 10)Motorized caravan	-0.27	0.00	-0.32	0.66	-0.31	0.67	-0.27	0.74	-0.27	0.74	0.49	0.09	-0.80	0.08	-0.31
relevel(VehBody, ref = 10)Panel van	0.22	0.00	0.24	0.35	0.24	0.36	0.22	0.37	0.22	0.37	0.15	0.29	0.09	0.68	0.24
relevel(VehBody, ref = 10)Roadster	-2.53	0.00	-2.43	0.33	-2.44	0.37	-2.53	0.63	-2.53	0.63	-0.53	0.60	-2.00	0.20	-2.53
relevel(VehBody, ref = 10)Station wagon	0.08	0.00	0.07	0.45	0.07	0.44	0.08	0.38	0.08	0.38	0.02	0.61	0.04	0.62	0.06
relevel(VehBody, ref = 10)Truck	0.22	0.00	0.21	0.26	0.21	0.25	0.22	0.20	0.22	0.20	-0.06	0.57	0.28	0.09	0.22
relevel(VehBody, ref = 10)Utility	0.05	0.00	0.04	0.74	0.04	0.74	0.05	0.68	0.05	0.68	-0.18	0.02	0.23	0.06	0.05
VehValue	0.05	0.00	0.06	0.09	0.06	0.09	0.05	0.10	0.05	0.10	0.03	0.17	0.04	0.29	0.06

All levels for all variables are calculated to have p value of 0,01

Comparison of Model Coefficients/Significance Values

PRICING GAME

Variables/Levels	Poisson Estimates	P value	Tweedie Opt Coeff	P value	Tweedie 1.5 Coeff	P value	Tweedie 1 Coeff	P value	Quasipoisson Coeff	P value	Frequency Coeff	P value	Severity Coeff	P value	Combined Coeff
(Intercept)	3.96	0.00	3.91	0.00	3.91	0.00	3.96	0.00	3.96	0.00	-2.19	0.00	6.32	0.00	4.13
drv_age1	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.06	0.00	0.00	0.01
drv_sex1M	-0.04	0.00	-0.05	0.10	-0.06	0.09	-0.04	0.20	-0.04	0.20	-0.04	0.04	0.00	0.95	-0.04
pol_bonus	1.20	0.00	1.24	0.00	1.24	0.00	1.20	0.00	1.20	0.00	0.80	0.00	0.32	0.00	1.12
pol_coverageMedian1	-0.49	0.00	-0.45	0.00	-0.45	0.00	-0.49	0.00	-0.49	0.00	-0.16	0.00	-0.29	0.00	-0.45
pol_coverageMedian2	-0.53	0.00	-0.50	0.00	-0.49	0.00	-0.53	0.00	-0.53	0.00	-0.20	0.00	-0.29	0.00	-0.49
pol_coverageMini	-1.08	0.00	-1.05	0.00	-1.04	0.00	-1.08	0.00	-1.08	0.00	-1.09	0.00	0.22	0.01	-0.87
relevel(pol_usage, ref = 4)AllTrips	0.44	0.00	0.38	0.33	0.38	0.35	0.44	0.16	0.44	0.16	0.32	0.15	0.03	0.90	0.36
relevel(pol_usage, ref = 4)Professional	0.13	0.00	0.11	0.05	0.11	0.06	0.13	0.01	0.13	0.01	0.14	0.00	-0.02	0.61	0.12
relevel(pol_usage, ref = 4)Retired	-0.10	0.00	-0.12	0.01	-0.12	0.01	-0.10	0.03	-0.10	0.03	-0.08	0.01	-0.06	0.08	-0.14
vh_age	-0.05	0.00	-0.05	0.00	-0.05	0.00	-0.05	0.00	-0.05	0.00	-0.04	0.00	-0.01	0.00	-0.05
vh_fuelGasoline	-0.15	0.00	-0.15	0.00	-0.15	0.00	-0.15	0.00	-0.15	0.00	-0.20	0.00	0.08	0.00	-0.12
vh_fuelHybrid	0.24	0.00	0.15	0.73	0.14	0.75	0.24	0.48	0.24	0.48	0.10	0.71	0.01	0.96	0.11
vh_value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Comparison of Model Coefficients/Significance Values

BRVEHINS

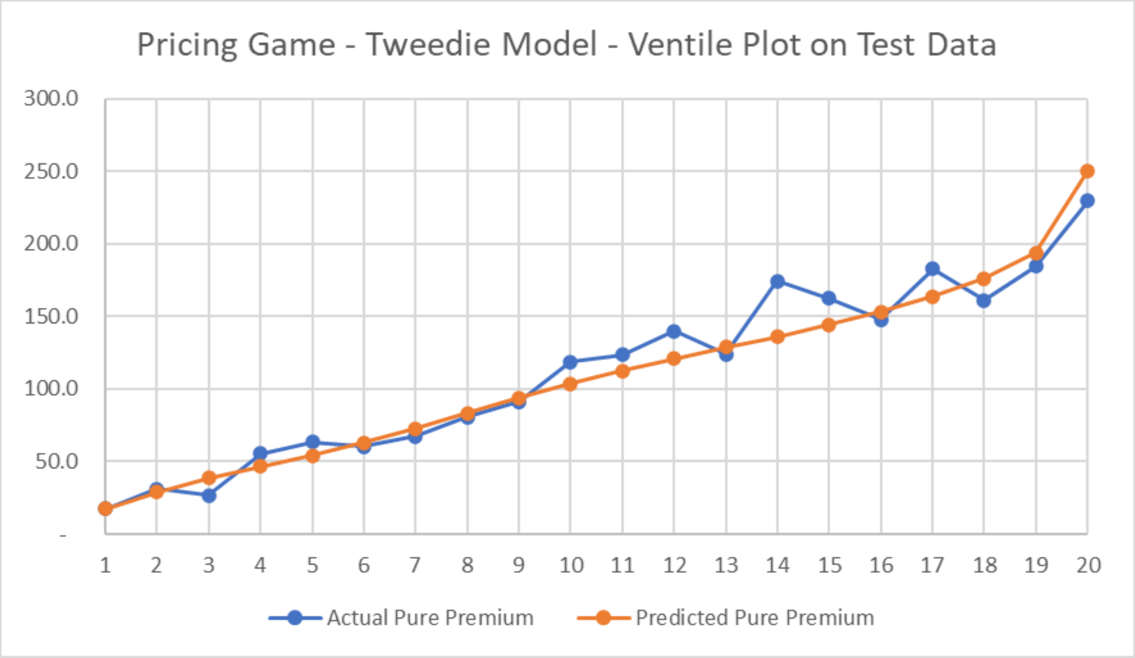
Variables/Levels	Poisson Estimates	P value	Tweedie Opt Coeff	P value	Tweedie 1.5 Coeff	P value	Tweedie 1 Coeff	P value	Quasipoisson Coeff	P value	Frequency Coeff	P value	Severity Coeff	P value	Combined Coeff
(Intercept)	6.84	0.00	6.85	0.00	6.84	0.00	6.84	0.00	6.84	0.00	-1.23	0.00	8.72	0.00	7.49
relevel(DrivAge, ref = 4)>55	-0.23	0.00	-0.23	0.00	-0.23	0.00	-0.23	0.00	-0.23	0.00	0.10	0.00	-0.18	0.00	-0.08
relevel(DrivAge, ref = 4)18-25	0.35	0.00	0.32	0.00	0.33	0.00	0.35	0.00	0.35	0.00	0.24	0.00	0.00	0.92	0.25
relevel(DrivAge, ref = 4)26-35	0.12	0.00	0.11	0.00	0.11	0.00	0.12	0.00	0.12	0.00	0.16	0.00	0.00	0.78	0.16
relevel(DrivAge, ref = 4)46-55	-0.03	0.00	-0.03	0.01	-0.03	0.01	-0.03	0.00	-0.03	0.00	0.12	0.00	-0.05	0.00	0.07
relevel(Gender, ref = 3)Female	-0.30	0.00	-0.28	0.00	-0.29	0.00	-0.30	0.00	-0.30	0.00	0.09	0.00	-0.25	0.00	-0.16
relevel(State, ref = 25)Acre	-0.15	0.00	-0.12	0.35	-0.13	0.31	-0.15	0.24	-0.15	0.24	-0.57	0.00	-0.28	0.00	-0.85
relevel(State, ref = 25)Alagoas	-0.14	0.00	-0.14	0.00	-0.14	0.00	-0.14	0.00	-0.14	0.00	-0.91	0.00	0.14	0.00	-0.78
relevel(State, ref = 25)Amapa	0.11	0.00	0.11	0.48	0.11	0.46	0.11	0.43	0.11	0.43	-0.61	0.00	-0.02	0.86	-0.63
relevel(State, ref = 25)Amazonas	-0.32	0.00	-0.31	0.00	-0.32	0.00	-0.32	0.00	-0.32	0.00	-0.66	0.00	-0.27	0.00	-0.93
relevel(State, ref = 25)Bahia	-0.08	0.00	-0.07	0.00	-0.07	0.00	-0.08	0.00	-0.08	0.00	-0.69	0.00	0.24	0.00	-0.45
relevel(State, ref = 25)Ceara	-0.20	0.00	-0.19	0.00	-0.19	0.00	-0.20	0.00	-0.20	0.00	-0.80	0.00	0.20	0.00	-0.59
relevel(State, ref = 25)Distrito Federal	-0.18	0.00	-0.17	0.00	-0.18	0.00	-0.18	0.00	-0.18	0.00	-0.70	0.00	-0.02	0.53	-0.71
relevel(State, ref = 25)Esperito Santo	-0.01	0.00	0.00	0.91	0.00	0.98	-0.01	0.83	-0.01	0.83	-0.46	0.00	-0.04	0.18	-0.50
relevel(State, ref = 25)Goias	0.09	0.00	0.08	0.00	0.08	0.00	0.09	0.00	0.09	0.00	-0.69	0.00	0.23	0.00	-0.46
relevel(State, ref = 25)Maranhao	-0.04	0.00	-0.04	0.41	-0.04	0.42	-0.04	0.44	-0.04	0.44	-0.62	0.00	0.08	0.09	-0.54
relevel(State, ref = 25)Mato Grosso	0.10	0.00	0.11	0.00	0.11	0.00	0.10	0.00	0.10	0.00	-0.68	0.00	0.23	0.00	-0.45
relevel(State, ref = 25)Mato Grosso do Sul	-0.11	0.00	-0.10	0.01	-0.10	0.01	-0.11	0.01	-0.11	0.01	-0.74	0.00	0.08	0.03	-0.66
relevel(State, ref = 25)Minas Gerais	-0.16	0.00	-0.17	0.00	-0.16	0.00	-0.16	0.00	-0.16	0.00	-1.01	0.00	0.27	0.00	-0.74
relevel(State, ref = 25)Para	0.05	0.00	0.05	0.23	0.05	0.21	0.05	0.20	0.05	0.20	-0.78	0.00	0.28	0.00	-0.49
relevel(State, ref = 25)Paraiba	-0.19	0.00	-0.19	0.00	-0.19	0.00	-0.19	0.00	-0.19	0.00	-0.88	0.00	0.11	0.01	-0.76
relevel(State, ref = 25)Parana	-0.02	0.00	-0.03	0.03	-0.03	0.08	-0.02	0.26	-0.02	0.26	-1.21	0.00	0.55	0.00	-0.66
relevel(State, ref = 25)Pernambuco	-0.35	0.00	-0.34	0.00	-0.34	0.00	-0.35	0.00	-0.35	0.00	-1.01	0.00	0.19	0.00	-0.82
relevel(State, ref = 25)Piaui	0.04	0.00	0.04	0.47	0.04	0.47	0.04	0.50	0.04	0.50	-0.52	0.00	-0.04	0.41	-0.56
relevel(State, ref = 25)Rio de Janeiro	-0.06	0.00	-0.07	0.00	-0.07	0.00	-0.06	0.00	-0.06	0.00	-0.73	0.00	0.32	0.00	-0.42
relevel(State, ref = 25)Rio Grande do Norte	-0.20	0.00	-0.19	0.00	-0.19	0.00	-0.20	0.00	-0.20	0.00	-0.52	0.00	-0.16	0.00	-0.68
relevel(State, ref = 25)Rio Grande do Sul	-0.09	0.00	-0.09	0.00	-0.09	0.00	-0.09	0.00	-0.09	0.00	-1.23	0.00	0.53	0.00	-0.70
relevel(State, ref = 25)Rondonia	-0.01	0.00	-0.03	0.87	-0.02	0.90	-0.01	0.97	-0.01	0.97	-0.37	0.00	-0.50	0.00	-0.87
relevel(State, ref = 25)Roraima	-0.73	0.00	-0.69	0.00	-0.70	0.00	-0.73	0.00	-0.73	0.00	-0.87	0.00	-0.51	0.00	-1.38
relevel(State, ref = 25)Santa Catarina	-0.20	0.00	-0.20	0.00	-0.20	0.00	-0.20	0.00	-0.20	0.00	-1.23	0.00	0.41	0.00	-0.82
relevel(State, ref = 25)Sergipe	-0.18	0.00	-0.18	0.00	-0.18	0.00	-0.18	0.00	-0.18	0.00	-0.71	0.00	-0.09	0.05	-0.80
relevel(State, ref = 25)Tocantins	0.18	0.00	0.18	0.01	0.18	0.00	0.18	0.00	0.18	0.00	-0.64	0.00	0.21	0.00	-0.43
VehAge	-0.05	0.00	-0.05	0.00	-0.05	0.00	-0.05	0.00	-0.05	0.00	0.02	0.00	-0.06	0.00	-0.05

4. Comparing Model Metrics

- Run the models on the same datasets using different assumptions:
  - Poisson
  - Tweedie
  - Quasi-Poisson
  - Frequency and Severity separately
- Check Model Performance
  - Average Ventile SE = $\frac{1}{20}\Sigma(Actual\ PP\ - Predicted\ PP)^2$
  - Lift = $\frac{Ventile\ 20\ Actual\ PP}{Ventile\ 1\ Actual\ PP}$
  - Gini Coefficient

Example Model Metrics

Ventile	Observed Pure Premium	Predicted Pure Premium	Ventile Squared Error	Exposures
1	17.6	17.7	0.0	998
2	31.3	29.2	4.6	999
3	26.7	38.7	143.4	999
4	55.5	46.6	78.6	999
5	63.3	54.0	85.9	999
6	60.4	62.8	5.9	999
7	67.4	72.8	29.9	999
8	80.9	83.2	5.6	999
9	91.1	94.0	8.6	999
10	118.6	103.9	215.4	999
11	123.8	112.7	121.9	999
12	140.1	121.0	363.8	999
13	124.2	128.7	19.8	999
14	174.6	136.0	1,492.1	999
15	162.4	144.3	328.6	999
16	147.9	153.4	30.2	999
17	182.7	163.8	356.3	999
18	161.4	176.4	225.4	999
19	184.5	194.0	90.2	999
20	229.9	250.7	433.0	999



Average VSE	***202.0***
Lift	***13.1***

Model Metrics Comparison

Pricing Game	Ave VSE	Lift	Gini
Poisson	149.4	13.08	0.298
Quasipoisson	149.4	13.08	0.298
Quasipoisson (excluding high p-values)	120.1	11.89	0.298
Tweedie	202.0	13.06	0.310
Tweedie (excluding high p-values)	226.1	12.60	0.309
Freq & Sev Combined	469.3	15.41	0.292
Freq & Sev Combined (exclude high p-values)	330.2	11.45	0.291

Ausprivauto	Ave VSE	Lift	Gini
Poisson	3,432.1	1.57	0.263
Quasipoisson	3,432.1	1.57	0.263
Quasipoisson (excluding high p-values)	2,487.6	1.93	0.351
Tweedie	3,351.5	1.54	0.263
Tweedie (excluding high p-values)	3,133.6	1.90	0.261
Freq & Sev Combined	3,716.5	1.60	0.263
Freq & Sev Combined (exclude high p-values)	2,515.9	1.51	0.263

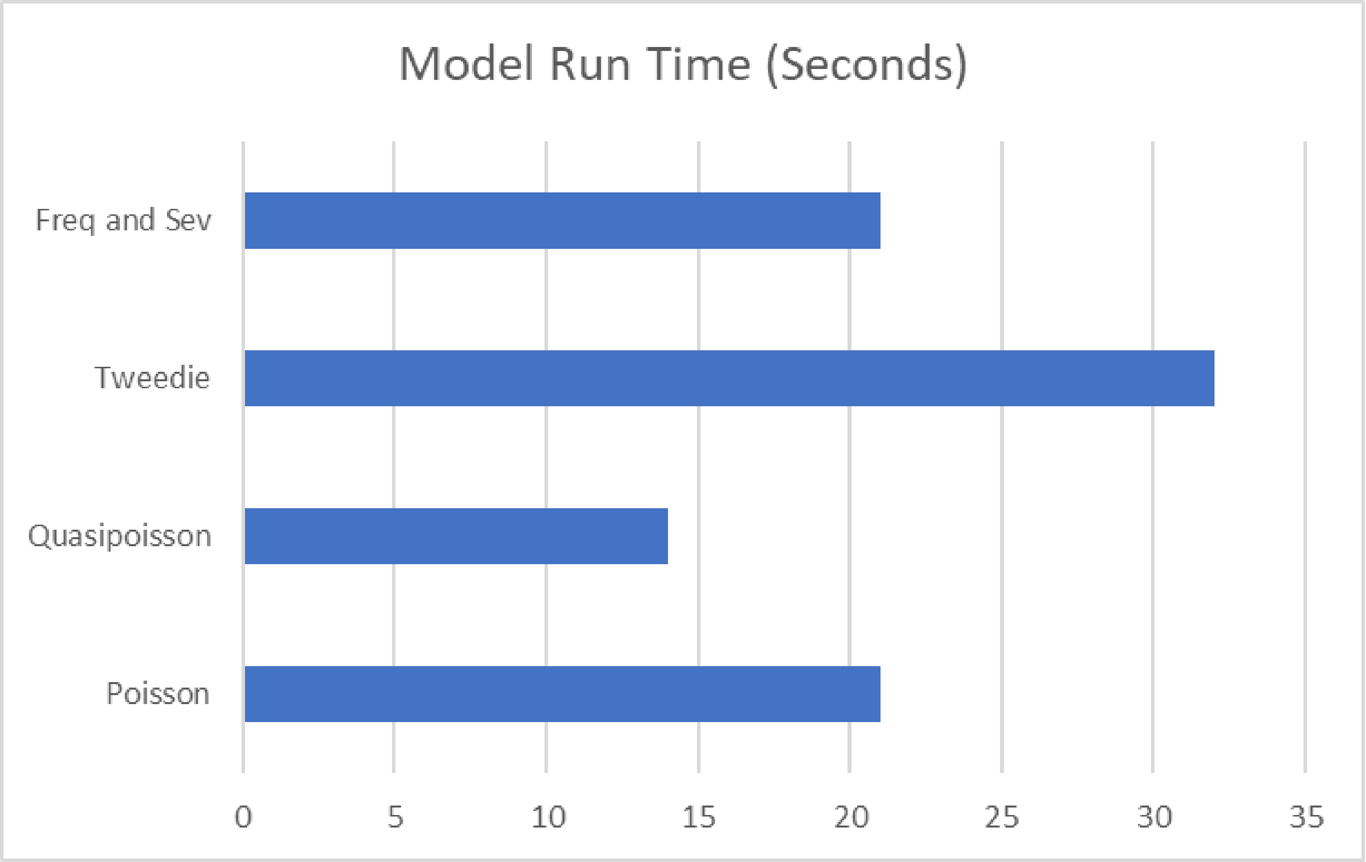
Brvehins	Ave VSE	Lift	Gini
Poisson	609.8	3.30	0.737
Quasipoisson	609.8	3.30	0.737
Tweedie	500.3	3.34	0.738
Freq &Sev Combined	366.3	3.26	0.738

5. Modeling Run Time

- Run the models on the same datasets using different assumptions:
  - Poisson
  - Tweedie
  - Quasi-Poisson
- Check Run Time via Timestamps in R

Model Run Times

Model	Seconds	Relative Time
Poisson	21	1.500
Quasipoisson	14	1.000
Tweedie	32	2.286
Freq and Sev	(17 + 4) = 21	1.500



6. Pure Premium Modeling Conclusions

- Tweedie
  - The standard pure premium distribution according to the CAS Monograph
  - Produces p-values useful for variable selection and regulator review
  - Slowest model run time
- Poisson
  - Generates similar coefficients and predictions
  - Produces p-values that are MUCH lower compared to other approaches (NOT as useful)
- Quassipoisson
  - Generates similar coefficients and predictions
  - Produces p-values useful for variable selection and regulator review
  - Fastest model run time in this exercise
  - Occasionally outperforms Tweedie in model metrics

Questions?