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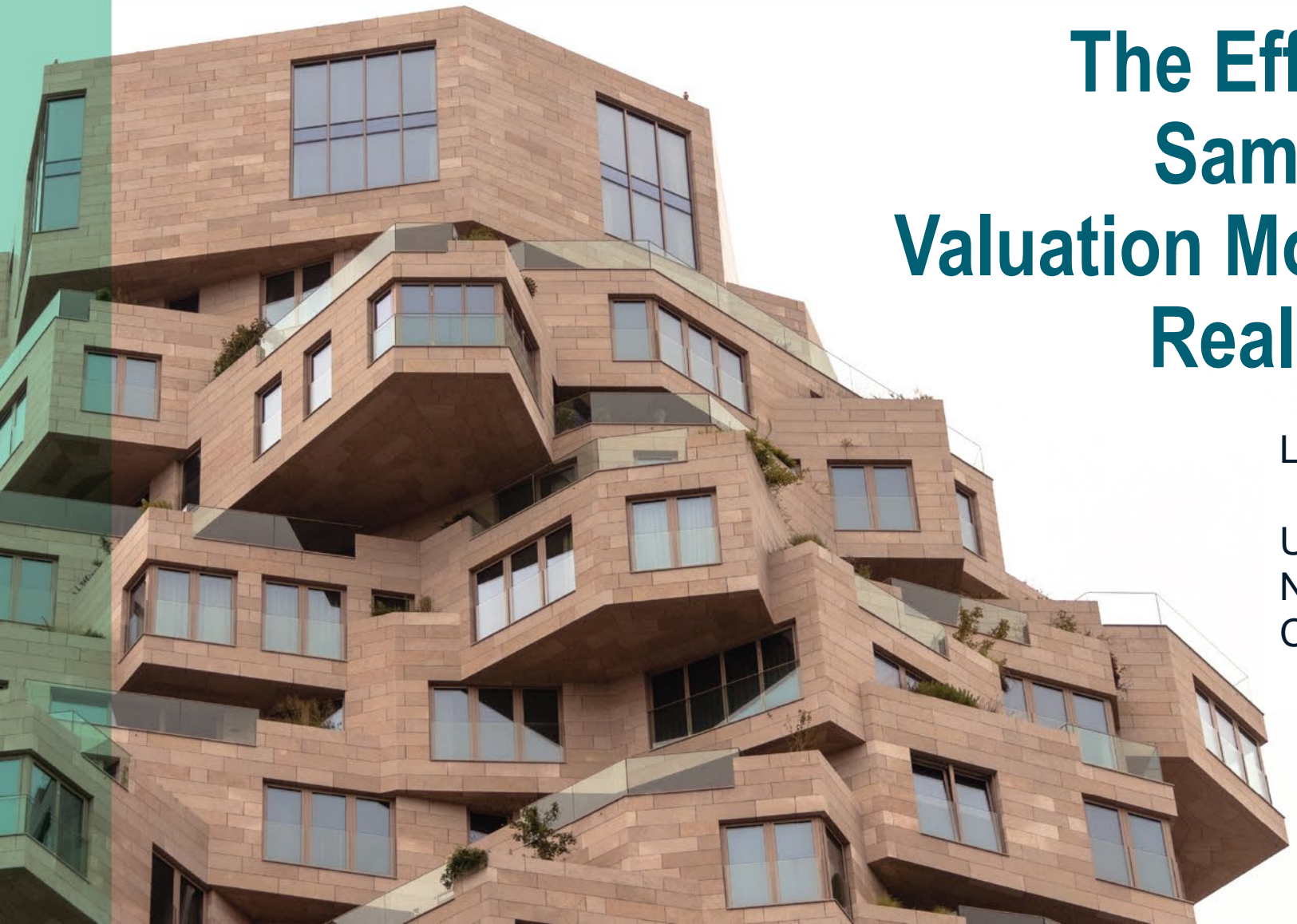
Amsterdam, The Netherlands · December 4 - 5, 2024
ASSESSMENT INNOVATION & COLLABORATION WITH A FOCUS ON AI



The Effects of Monte Carlo Sampling on Automated Valuation Model Performance in Real Estate Assessment

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CART

IAAO

IIFI IPTI
International Property Tax Institute

Content

- Uncertainty and risk
- The problem statement
- The Monte Carlo method
- Statistical theory
- Automated Valuation Models
- The research project
- Results
- Further research
- Conclusions

Uncertainty and Risk

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Uncertainty and Risk

- Uncertainty is an integral part of any valuation
  - Uncertainty increases if a market is non-efficient
  - Real estate markets are a prime example of non-efficient markets:
    - Only few properties sell each year compared to the complete stock
    - Transparency is relatively low
      - Transaction data
      - Object data
    - A sale materializes under very specific circumstances
  - Uncertainty increases if a real estate market is less mature and more opaque

Uncertainty and Risk

- **Normal uncertainty:** the uncertainty arising from the methods used, the data used and from the assessment of current and future market conditions. Normal uncertainty is therefore the uncertainty that emerges with the choices made in the valuation process as well as the describable uncertainty of the conditions the valuation has to be made in.
- **Abnormal uncertainty:** abnormal uncertainty is uncertainty that arises from unusuality, such as extreme market conditions in the event of financial bear or bull markets. However, highly unusual characteristics of a single property also contributes to abnormal uncertainties.
- Risk is described and quantified uncertainty:
  - Verbal communication
  - Risk scoring
  - **Statistical quantification**

The problem statement

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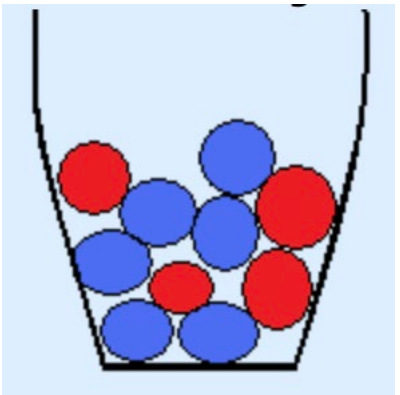
The problem statement

- Automated valuation modelling
  - Split data in train and hold out set
  - Commonly a 80-20 split
  - Preventing overfitting to ensure consistency in sold and unsold properties
- How big is this problem?
- $\binom{n}{k}$
- $\frac{n!}{k!(n-k)!}$
- In which n is the population and k is the size of the sample



The problem statement

Total population	Number of sales in the hold-out set	Total different configurations of the hold out set
10	2	45
100	20	$5.359833704e^{20}$
1000	200	$6.61715556e^{215}$

- Clearly not every possible configuration can be checked for model performance
- Concepts from statistics and probability theory can aid to uncover some of this normal uncertainty

Theory

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Monte Carlo method

- Repeating a probalistic process many times

Casinos Not in the Business of Being Fair

6.0002 LECTURE 6 17

Comparing the Games

```
Simulate 20 trials of 1000 spins each
Exp. return for Fair Roulette = 6.56%
Exp. return for European Roulette = -2.26%
Exp. return for American Roulette = -8.92%

Simulate 20 trials of 10000 spins each
Exp. return for Fair Roulette = -1.234%
Exp. return for European Roulette = -4.168%
Exp. return for American Roulette = -5.752%

Simulate 20 trials of 100000 spins each
Exp. return for Fair Roulette = 0.8144%
Exp. return for European Roulette = -2.6506%
Exp. return for American Roulette = -5.113%

Simulate 20 trials of 1000000 spins each
Exp. return for Fair Roulette = -0.0723%
Exp. return for European Roulette = -2.7329%
Exp. return for American Roulette = -5.212%
```

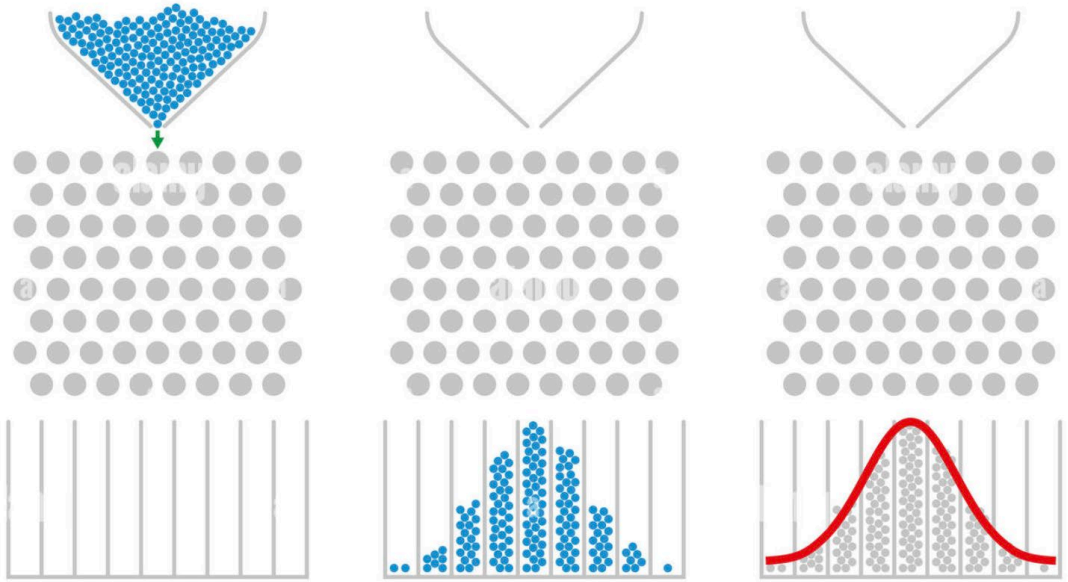
6.0002 LECTURE 6 19

- MIT open course (Introduction To Computational Thinking And Data Science) (Guttag, 2016)

Statistical concepts

- Law of Large Numbers
  - the mean of all means from the different Monte Carlo runs will approach the true mean of the population if the number of Monte Carlo runs increases towards infinity

- Central Limit Theorem
  - states that when independent random variables are plotted against their frequency, this frequency distribution approaches a normal distribution



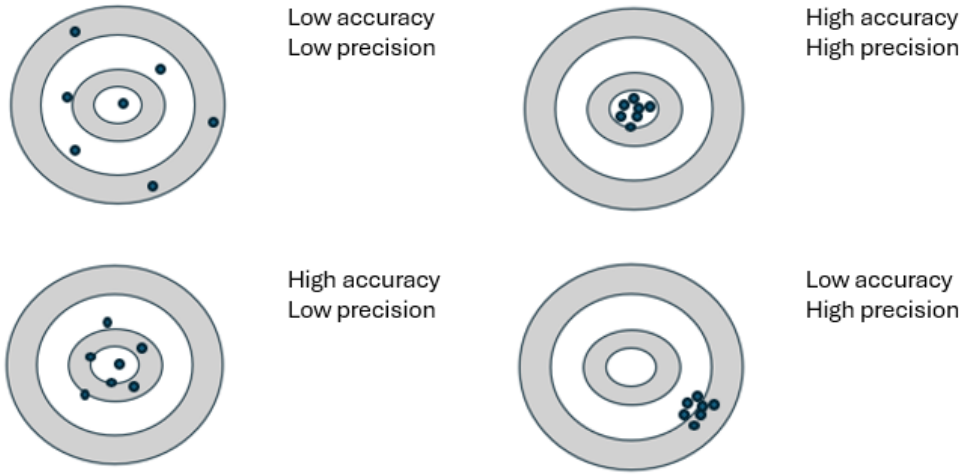
Automated valuation models

- Traditional
  - Regression based (logarithmic transformations are common)
- Artificial intelligence
  - Neural networks
  - Gradient boosting machines
  - Random forrest
  - Etc.
- Spatially aware models
  - GWR
  - SLM
  - Etc.
- Cross breed models

Model performance

- Measured by:
  - Accuracy (Median Ratio)
  - Precision (COD)
  - Consistency (Horizontal & vertical)
- Vertical inequity:
  - **Progressive vertical inequity:** (increasing) homes in the higher market segment bear relatively higher tax burdens. In other words, model-based valuation has resulted in relatively lower ratios in the lower segment while ratios in the higher segment are higher
  - **Regressive vertical inequity**: (declining) homes in the lower market segment bear relatively higher tax burdens. In other words, model-based valuation has resulted in relatively higher ratios in the lower segment while ratios in the higher segment are lower.

In this study measured by PRD & PRB



The research project

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Data

- Data provided by the Netherlands Council for Real Estate Assessment:
- Municipality of Helmond:
  - Midsize Dutch city (100,000 inhabitants)
  - Highly homogeneous
- The sales data:
  - 5513 usable sales
  - Between January 2017 and December 2021
- With an 80-20 split:
  - $2.918067415e^{1196}$

The analysis

- 750 runs for each model
- 9-week calculation time for 2 virtual machines
- Three AVMs
  - Traditional (MRA)
  - Gradient boosting machine (GBM)
  - Geographically weighted regression (GWR)
- Collect model performance indicators for MR, COD, PRD & PRB
- Quasi random
  - Samples drawn by assigning integers without the use of a randomizing algorithm

Results

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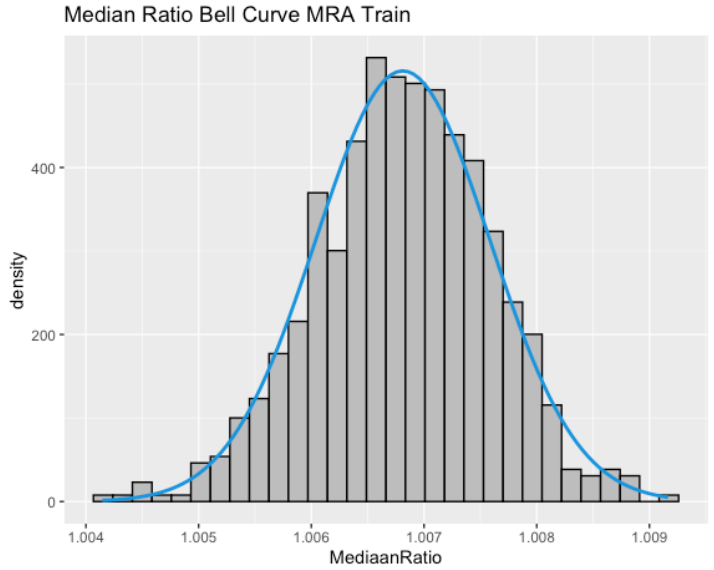
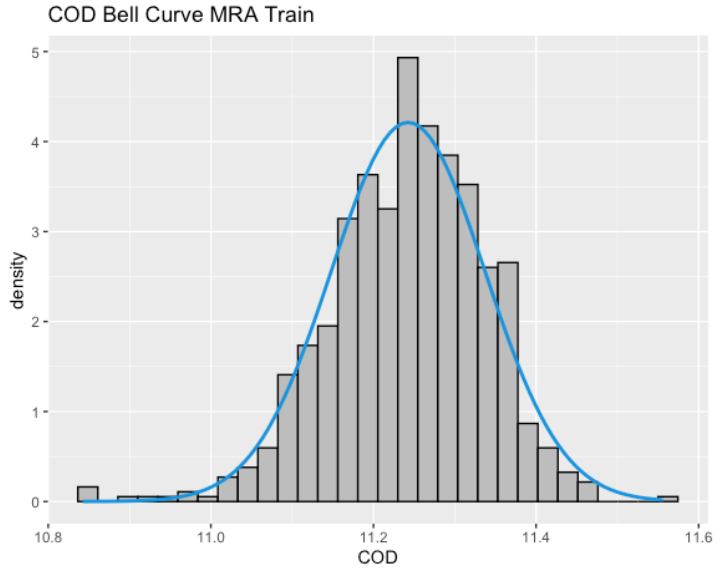
Monte Carlo

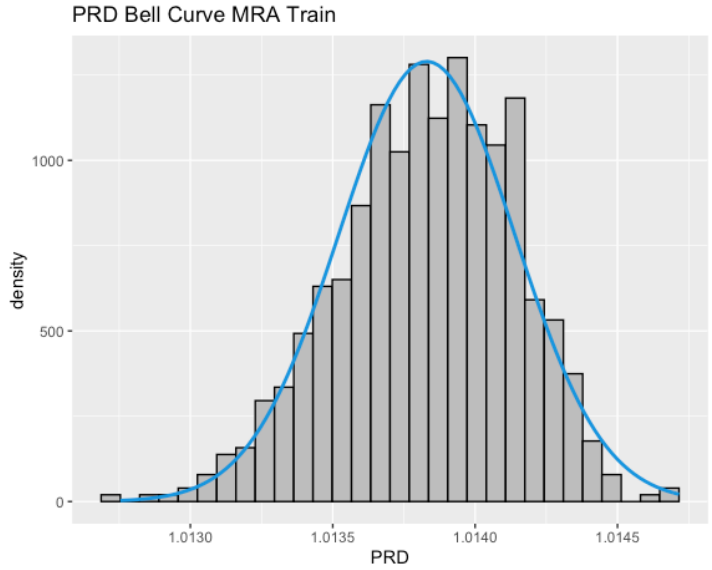

0
0.5
1 km
Frankrijk
Monte-
Carlo
casino
Haven van
Monaco
La
Condamine
MONACO
paleis
Fontvieille
Haven van
Fontvieille
Middellandse Zee

Results – MRA In sample

MRA Train						
	Min	Mean	Median	Max	Range	Standard deviation
Median Ratio	1.004	1.007	1.007	1.009	0.005	0.0007736111
COD	10.84	11.24	11.25	11.56	0.72	0.09469943
PRD	1.013	1.014	1.014	1.015	0.002	0.0003093028
PRB	0.001596	0.002970	0.002998	0.007762	0.009358	0.001613997
PRB Significance	0.05244	0.48467	0.45843	0.99787	0.94543	0.2211843
PRB* (N=X)	X	X	X	X	X	X







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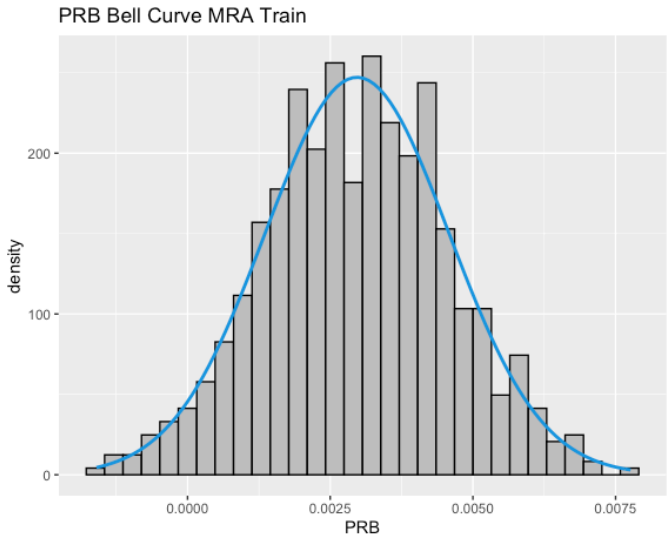
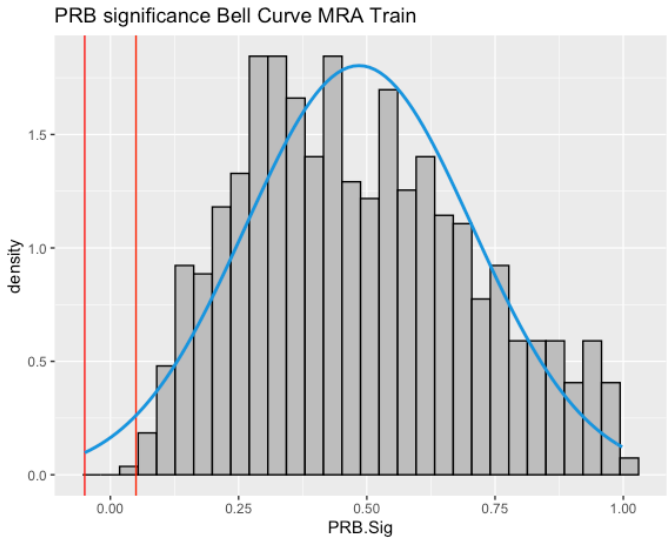
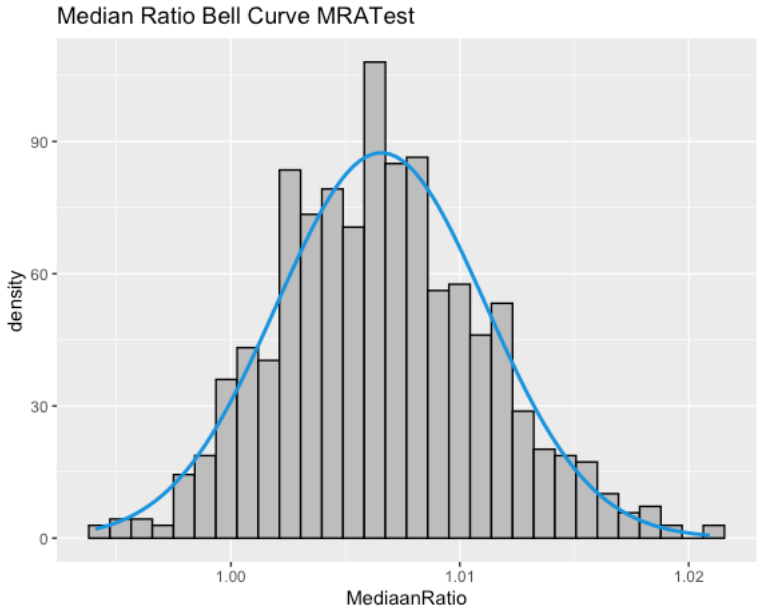
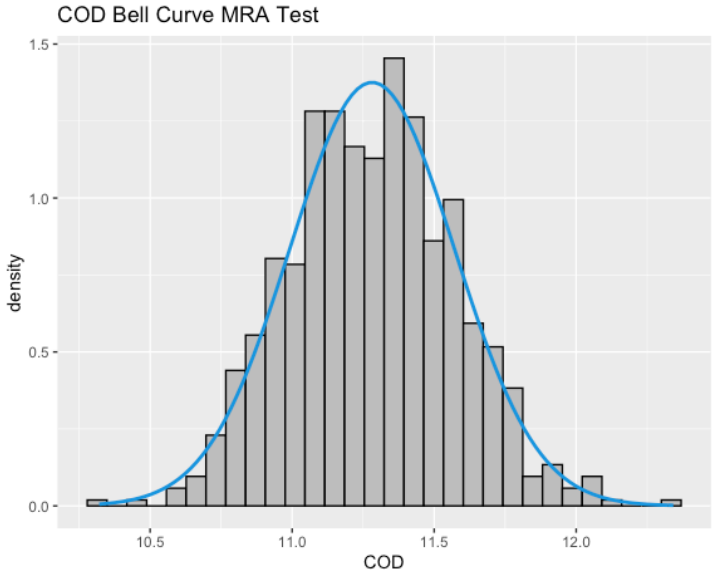


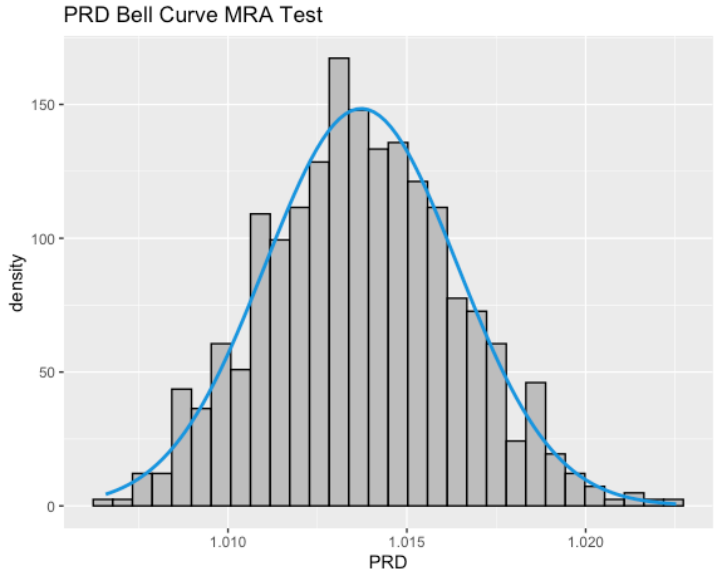


Results – MRA Hold out

MRA Test						
	Min	Mean	Median	Max	Range	Standard deviation
Median Ratio	0.9941	1.0066	1.0065	1.0209	0.0268	0.004562864
COD	10.32	11.28	11.28	12.34	2.02	0.2900147
PRD	1.007	1.014	1.014	1.021	0.016	0.002687624
PRB	-0.032424	0.003909	0.004198	0.029959	0.062383	0.01029577
PRB Significance	0.0000686	0.3948077	0.3396265	0.9984932	0.9984246	0.301492
PRB* (N=113)	-0.03242	0.01205	0.01872	0.02996	0.06208	0.01722928







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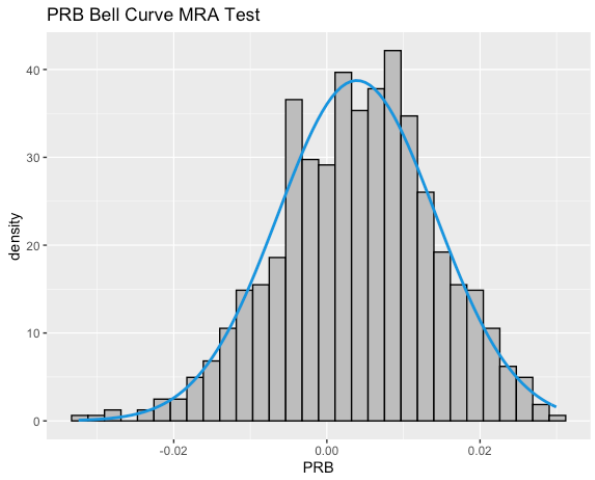
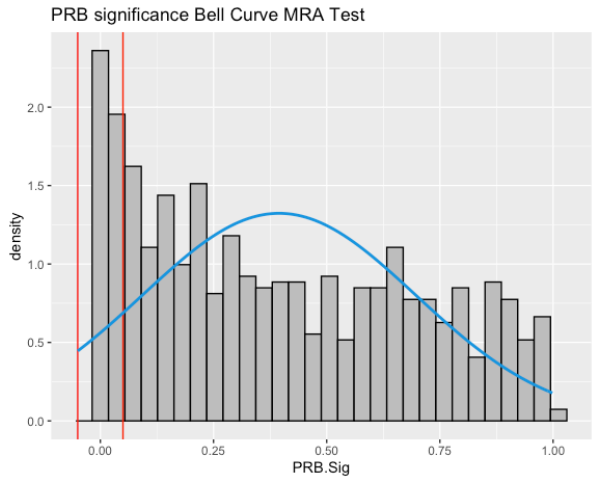
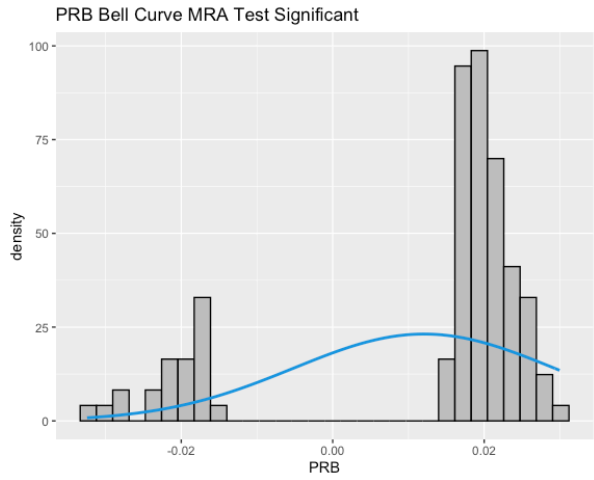
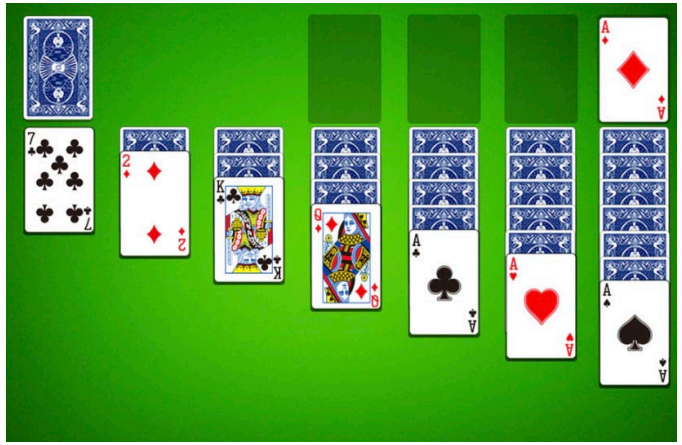




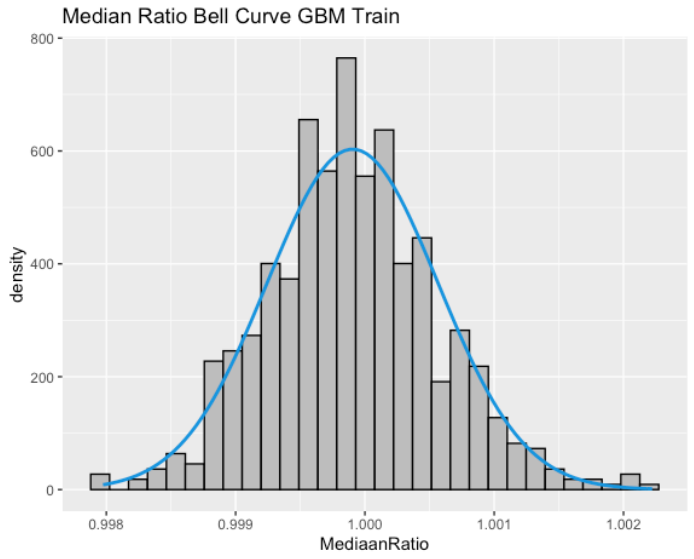


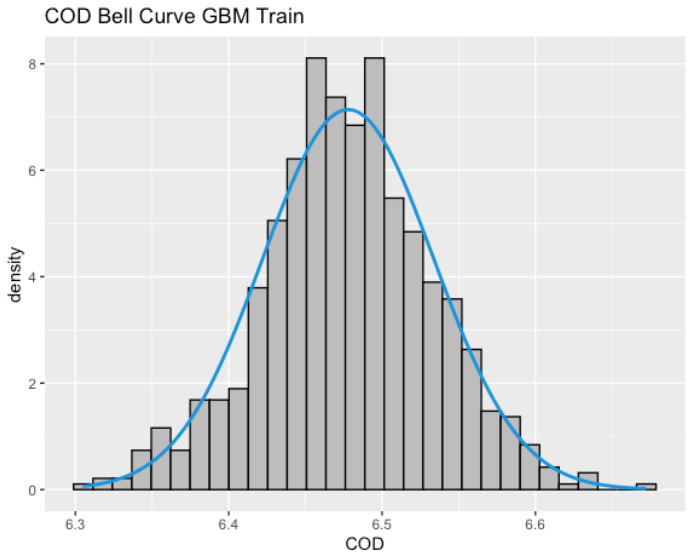
Monte Carlo

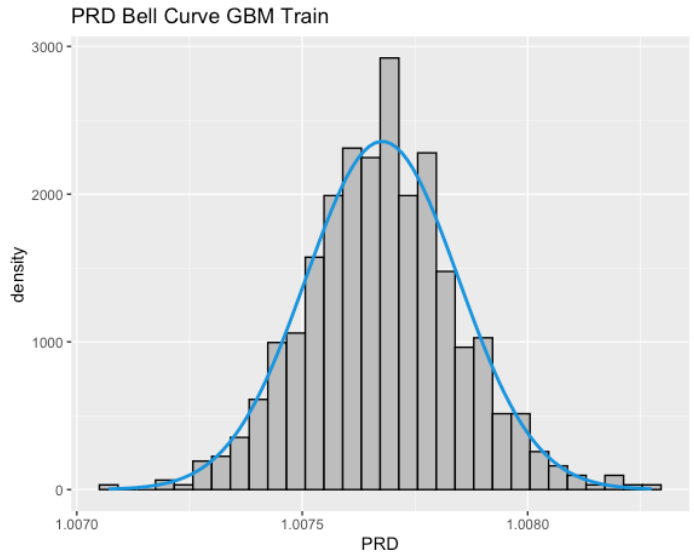


Results – GBM In sample

GBM Train						
	Min	Mean	Median	Max	Range	Standard deviation
Median Ratio	0.9980	0.9999	0.9999	1.0022	0.0042	0.0006614146
COD	6.305	6.478	6.478	6.672	0.367	0.05586565
PRD	1.007	1.008	1.008	1.008	0.001	0.0001692728
PRB	-0.02347	-0.02103	-0.02101	-0.01877	0.0047	0.0007780502
PRB Significance	1.000e-23	1.807e-18	9.498e-20	1.442e-16	1.442e-16	8.42094e-18
PRB* (N=X)	X	X	X	X	X	X







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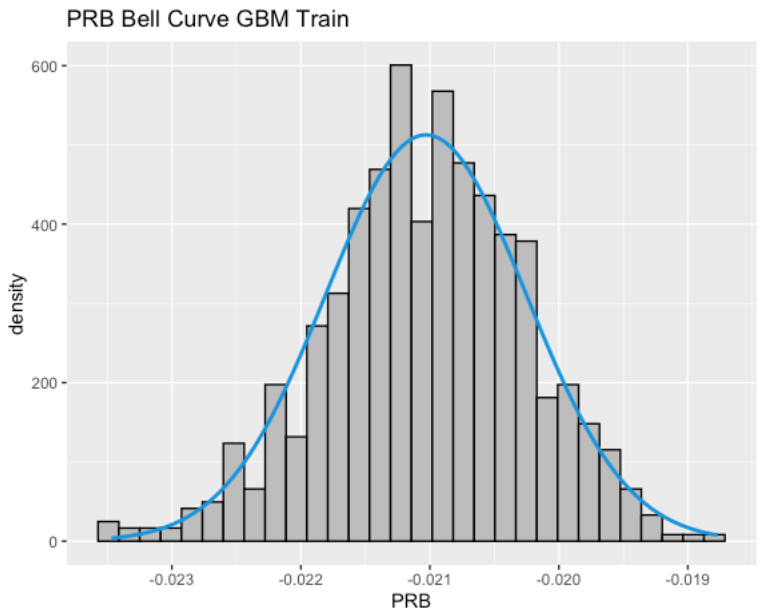
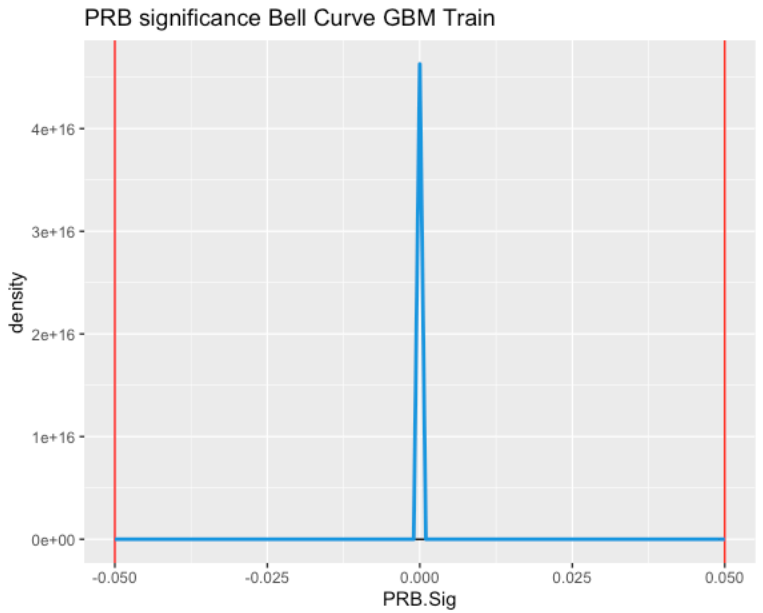
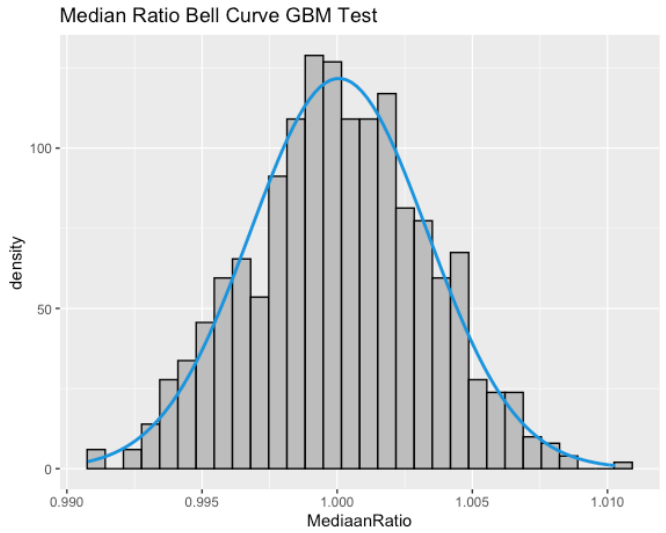
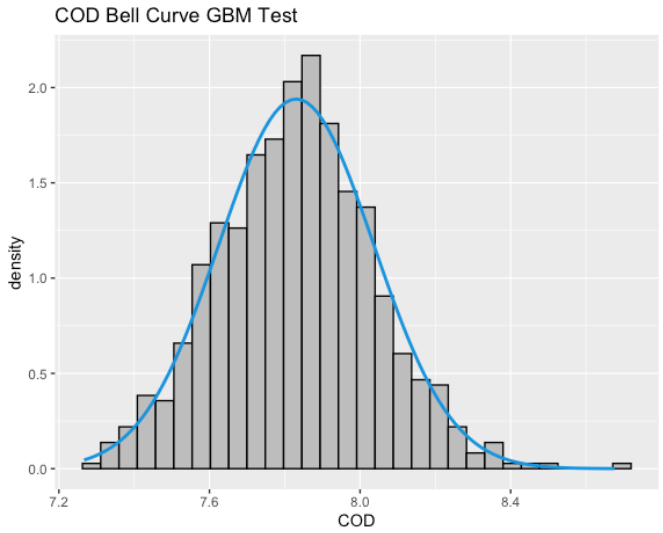


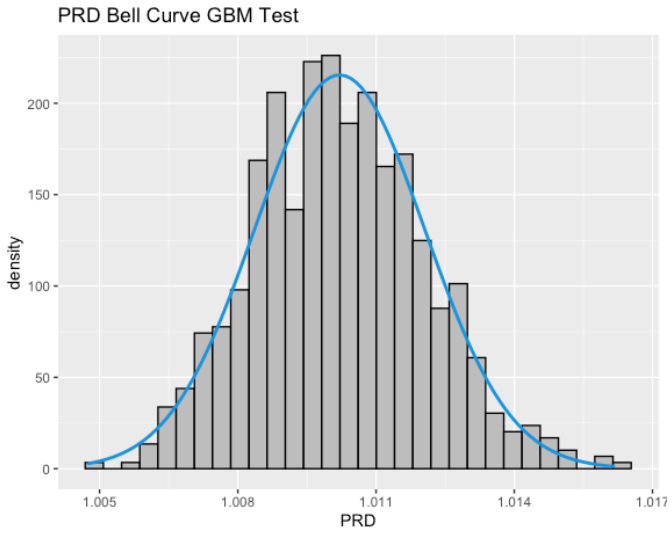


Results – GBM Hold out

GBM Test						
	Min	Mean	Median	Max	Range	Standard deviation
Median Ratio	0.9908	1.0001	1.0001	1.0103	0.0195	0.003276783
COD	7.267	7.831	7.834	8.676	1.409	0.20567
PRD	1.005	1.010	1.010	1.016	0.011	0.001851493
PRB	-0.043532	-0.021018	-0.020883	0.001272	0.044804	0.006997613
PRB Significance	0.0000000	0.0174514	0.0002450	0.8264082	0.8264082	0.06478129
PRB* (N=690)	-0.04353	-0.02211	-0.02154	-0.01142	0.03211	0.006140605







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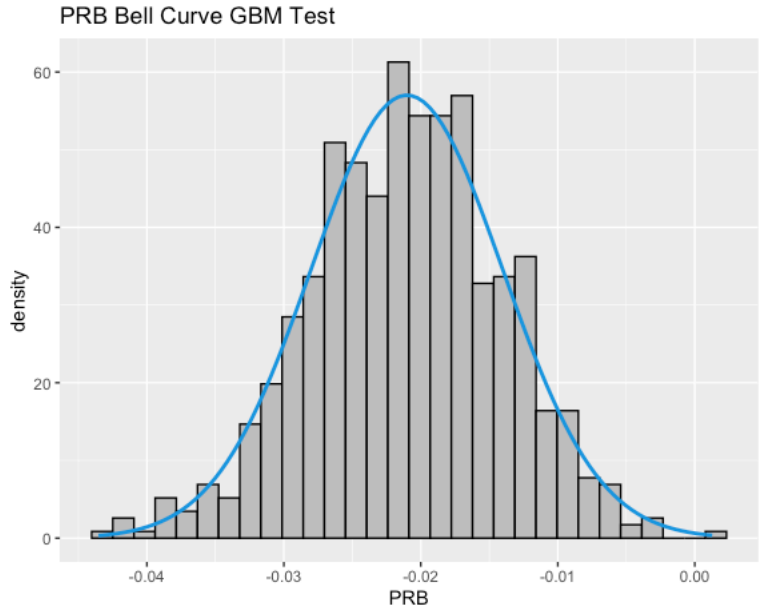
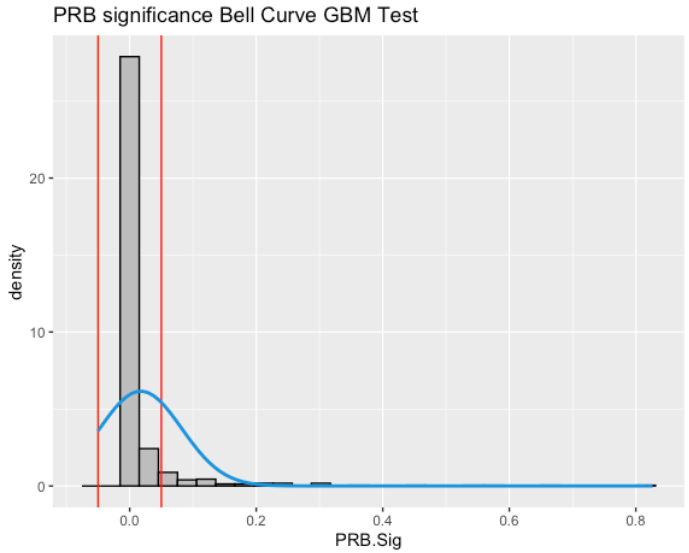
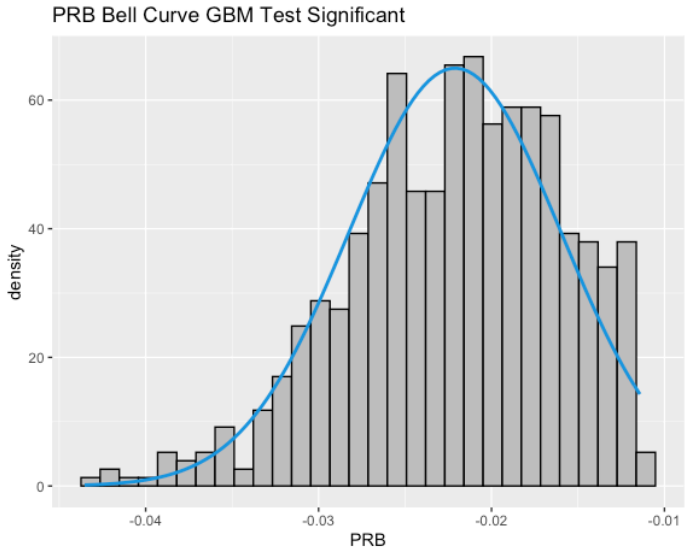




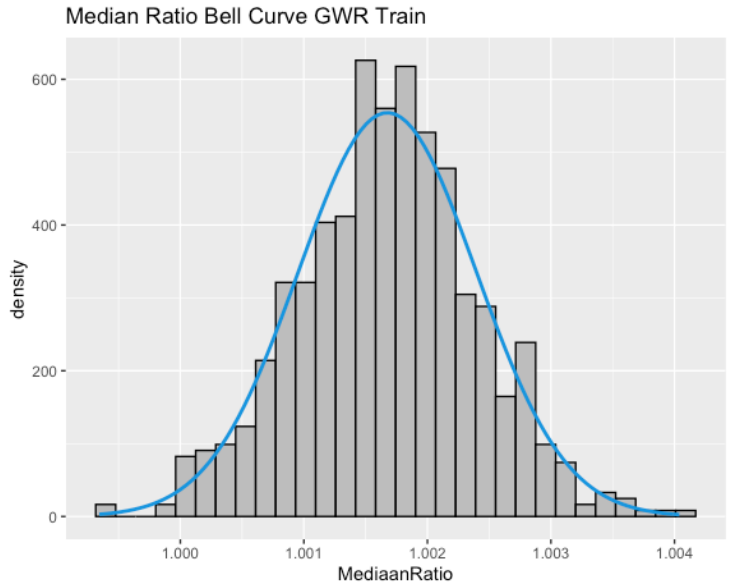


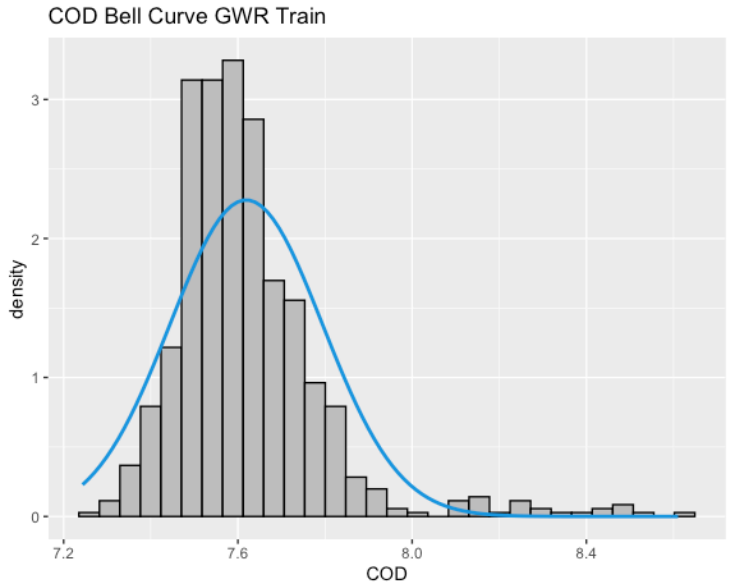
Monte Carlo

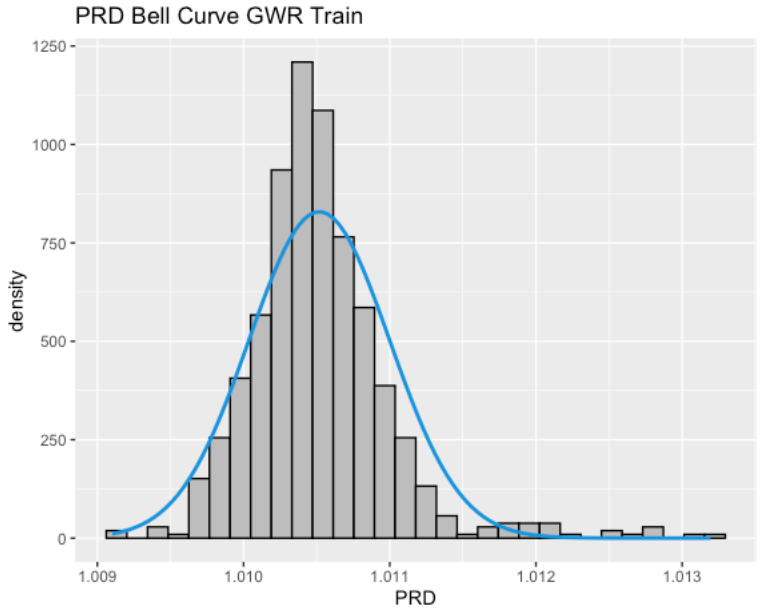
- Not novel, been done before
- Most notably to estimate π
- Also used in Italy before 1940
- More feasible after the advent of computers

Results – GWR In sample

GWR Train						
	Min	Mean	Median	Max	Range	Standard deviation
Median Ratio	0.9993	1.0017	1.0017	1.0040	0.0047	0.0007199143
COD	7.243	7.619	7.590	8.610	1.367	0.1752143
PRD	1.009	1.011	1.010	1.013	0.004	0.000481204
PRB	-0.02625	-0.02094	-0.02109	0.05842	0.08467	0.003160465
PRB Significance	0.000e+00	2.374e-06	0.000e+00	1.781e-03	1.781e-03	6.502048e-05
PRB* (N=X)						







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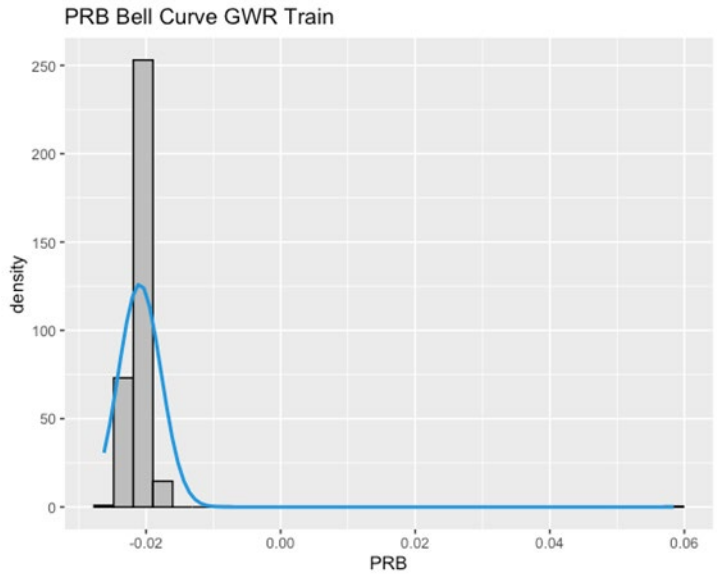
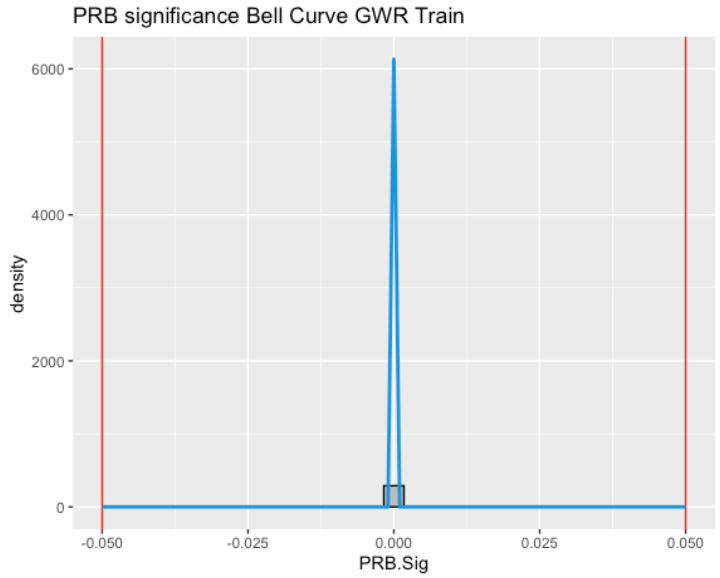
PRB* (N=X)						

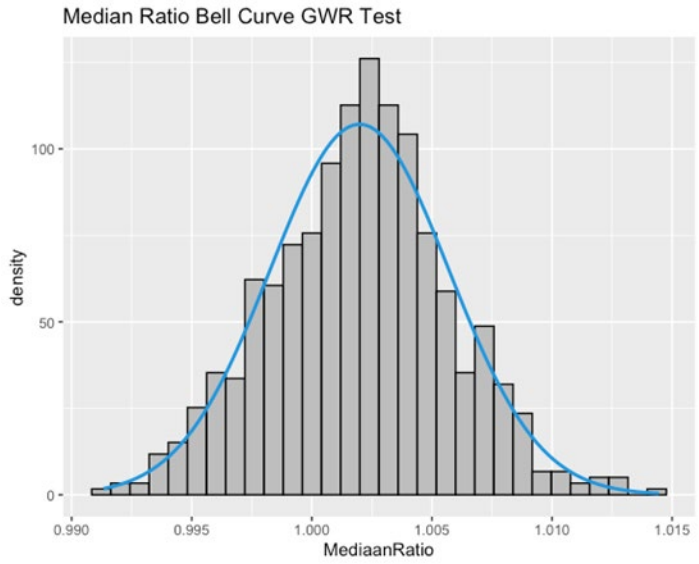


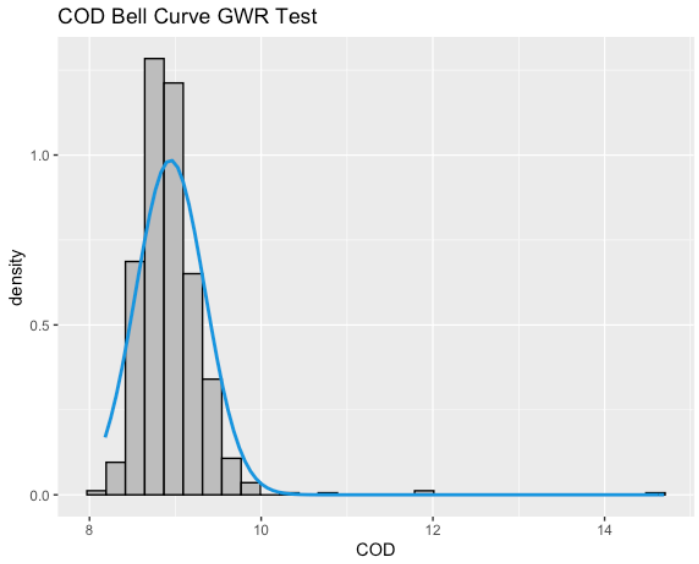


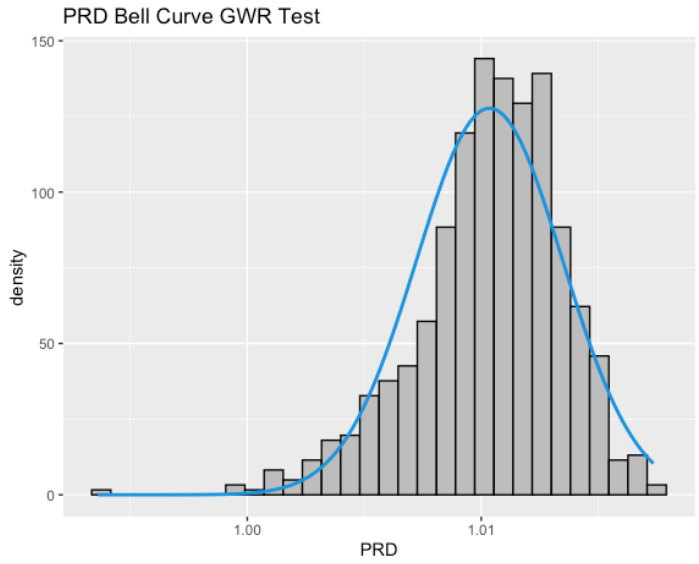
Z-score (PRB>0.05)= 25.1039
P(x<0.0584)≈1

Results – GBM Hold out

GWR Test (Calculation errors removed N=4)						
	Min	Mean	Median	Max	Range	Standard deviation
Median Ratio	0.9913	1.0020	1.0021	1.0145	0.0232	0.003724557
COD	8.182	8.943	8.887	14.693	6.511	0.4049825
PRD	0.9936	1.0104	1.0107	1.0174	0.0238	0.003122602
PRB	-0.0420971	-0.0081825	-0.0099498	0.0695872	0.1116843	0.01403782
PRB Significance	0.000000	0.215510	0.067511	0.996947	0.996947	0.2813443
PRB* (N=347)	-0.04210	-0.01451	-0.01822	0.06959	0.11169	0.01685983







Results – GBM Hold out

Z-score (PRB >0.05) = 4,98819
P(x<0,06959) ≈1

GWR Test (Calculation errors removed N=4)						
	Min	Mean	Median	Max	Range	Standard deviation
Median Ratio	0.9913	1.0020	1.0021	1.0145	0.0232	0.003724557
COD	8.182	8.943	8.887	14.693	6.511	0.4049825
PRD	0.9936	1.0104	1.0107	1.0174	0.0238	0.003122602
PRB	-0.0420971	-0.0081825	-0.0099498	0.0695872	0.1116843	0.01403782
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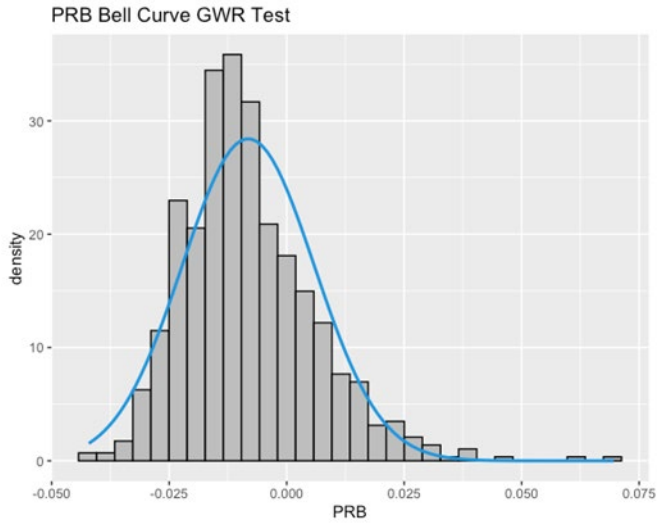
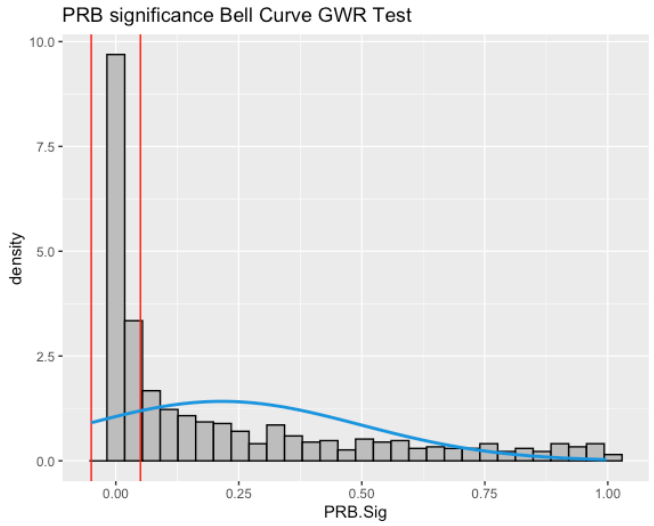
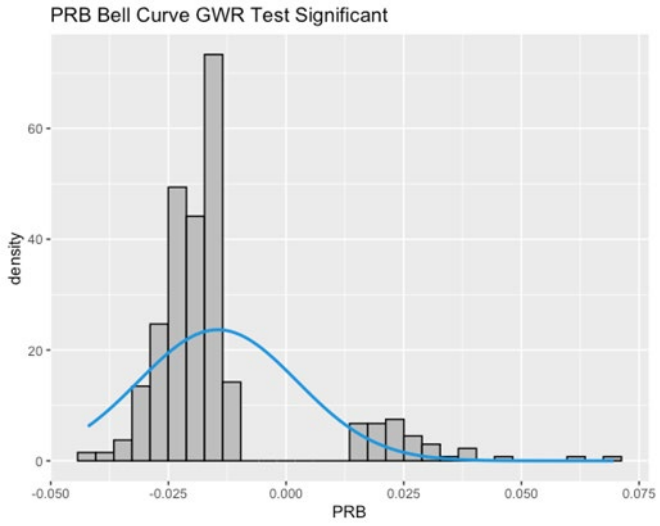
PRB* (N=347)	-0.04210	-0.01451	-0.01822	0.06959	0.11169	0.01685983



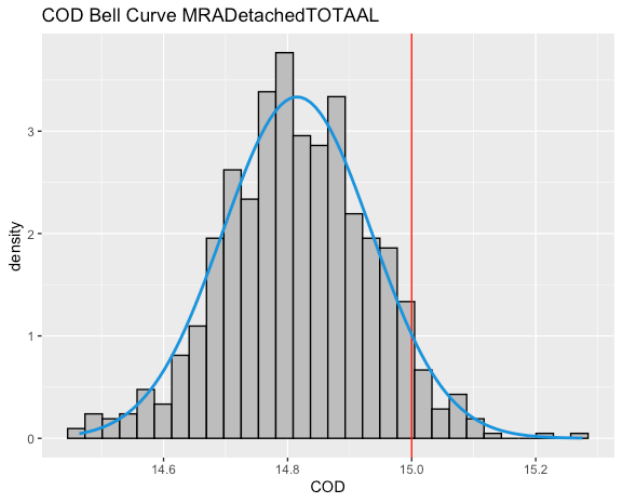




Results

- One last telling example:

MRA Detached Total						
	Min	Mean	Median	Max	Range	Standard deviation
Median Ratio	0.9976	1.0090	1.0090	1.0178	0.0202	0.003210438
COD	14.46	14.82	14.81	15.28	0.82	0.1196332
PRD	1.041	1.048	1.048	1.051	0.010	0.001326269
PRB	-0.3138	-0.2855	-0.2864	-0.2167	0.0971	0.01207809
PRB Significance	0.000e+00	2.342e-42	0.000e+00	1.755e-39	1.755e-39	6.409237e-41
PRB* (N=X)						



Z-score (COD>15) = 3,84509
P(X<15.28) ≈ 0,99994

Further research and Conclusions

INTERNATIONAL RESEARCH SYMPOSIUM

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Further research

- Research into the influence of different Monte Carlo methods (markov chain, true random)
- Research into the behavior of regression-based model performance metrics under the application of Monte Carlo sampling
- Research into the legal implications of the application
- Research into the the relation between the Monte Carlo sampling method, bootstrapping and confidence intervals
- Application of the approach to emerging markets and data of lesser quality

Conclusions

- Law of large numbers and central limit theorem are indeed observed
- The application of Monte Carlo methods allows for the use of inferential statistics:
  - Ultimately it changes the question of whether an AVM is compliant into the question of how probable an AVM is to be complient to the IAAO Standard on Ratio Studies
- GBM is the preferred model with the least variability in the model performance indicators

Acknowledgments

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Questions

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