# Measuring the Impact of a Lower BAC in Utah

## A Frequentist and Bayesian Comparison

# Introduction

## 0.05 BAC impact is measured by DUI related collisions

- **What:**
  - Utah lowered it’s BAC limit on 2018-12-30 from 0.08% to 0.05%
- **Expectations:**
  - The number alcohol related collisions and collisions involving death will decrease.
- **How to measure:**
  - We look at weekly DUI related collisions in Utah from 2015-01-01 to 2019-03-31

# Methodology

## We compare Frequentist and Bayesian Methodologies

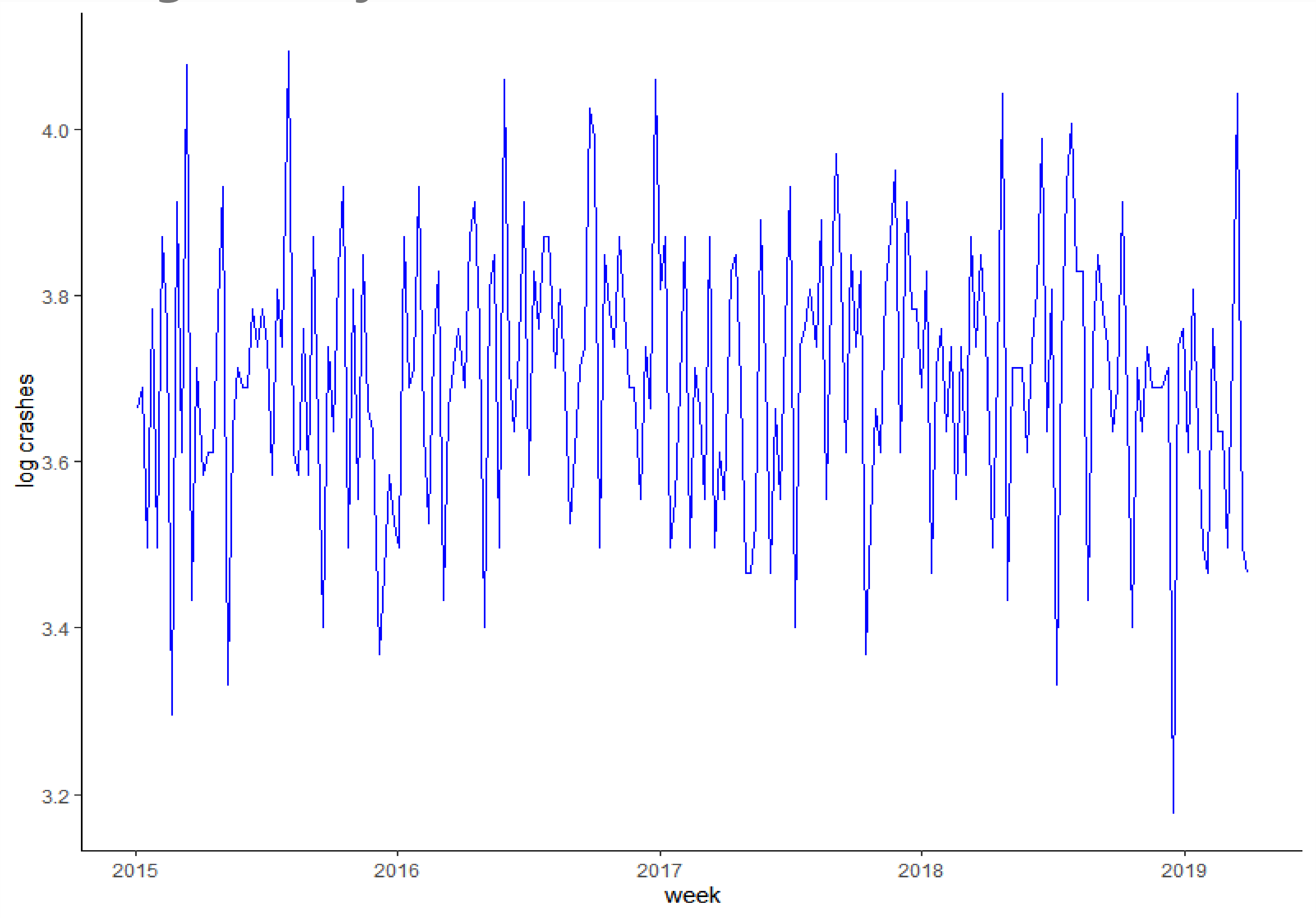
- **Frequentist**
  1. Identify plausible ARIMA model on pre-intervention data
  2. Run model on full series with a treatment binary included
  3. Ensure quality measures hold (i.e. residual checks, significance, convergence)
  4. Evaluate treatment binary

- **Bayesian**
  1. Build several state-space models on the full dataset and evaluate on:
     - RMSE, RMSE on a holdout, R-Square, Harvey's GOF, Posterior Predictive Checks
  2. Include treatment binary and evaluate impact based on:
     - Posterior Inclusion Probability
     - HPD interval given inclusion
  3. **Robustness Check:** Pre-built Bayesian State-Space Causal Impact Analysis

# Frequentist Approach: Unit Root Testing

## Perform visual inspection as first step of Unit Root Tests

### Log Weekly DUI Collisions




- No obvious deterministic trend
- Stationary test to include drift
- Seasonality potentially exists

# Frequentist Approach: Unit Root Testing

## HEGY tests for unit roots at each seasonal frequency

- **Seasonal Unit Root Example: SAR(1)**

$$y_t = \alpha y_{t\text{-}52} + \varepsilon$$
$$\alpha = 1$$

- **HEGY Test**
  - $H_o$: Unit Root
  - Test for a unit root at each seasonal frequency

# Frequentist Approach: Unit Root Testing

## HEGY statistics on level data show seasonal unit roots

- $H_o$: Unit Root

### HEGY Test Statistics

| | test statistic | p-value | | | test statistic | p-value | |
|---|---|---|---|---|---|---|---|
| t_1 | -2.68 | 0.061 | | F_31:32 | 1.85 | 0.110 | |
| t_2 | -1.16 | 0.236 | | F_33:34 | 2.24 | 0.073 | |
| F_3:4 | 1.82 | 0.113 | | F_35:36 | 2.09 | 0.085 | |
| F_5:6 | **3.30** | **0.025** | * | F_37:38 | 1.92 | 0.102 | |
| F_7:8 | 1.46 | 0.169 | | F_39:40 | 1.57 | 0.151 | |
| F_9:10 | **2.64** | **0.048** | * | F_41:42 | **4.89** | **0.005** | ** |
| F_11:12 | **4.18** | **0.009** | ** | F_43:44 | **5.53** | **0.003** | ** |
| F_13:14 | 1.93 | 0.102 | | F_45:46 | **3.84** | **0.014** | ** |
| F_15:16 | 0.34 | 0.582 | | F_47:48 | 1.91 | 0.103 | |
| F_17:18 | **2.81** | **0.041** | * | F_49:50 | 1.94 | 0.101 | |
| F_19:20 | **2.81** | **0.041** | * | F_51:52 | 0.41 | 0.531 | |
| F_21:22 | 0.83 | 0.331 | | F_2:52 | 3.67 | 0.253 | |
| F_23:24 | 1.13 | 0.243 | | F_1:52 | **3.78** | **0.000** | *** |
| F_25:26 | 2.49 | 0.056 | | | | | |
| F_27:28 | 0.42 | 0.525 | | | | | |
| F_29:30 | **3.59** | **0.018** | ** | | | | |

Sig. at 0.05
Insignificant

# Frequentist Approach: Unit Root Testing

## HEGY statistics on 1 seasonally difference show no unit roots

- $H_o$: Unit Root

### HEGY Test Statistics

| | test statistic | p-value | | | test statistic | p-value | |
|---|---|---|---|---|---|---|---|
| t_1 | -2.68 | 0.061 | | F_31:32 | 1.85 | 0.110 | |
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| F_23:24 | 1.13 | 0.243 | | F_1:52 | 3.78 | 0.000 | *** |
| F_25:26 | 2.49 | 0.056 | | | | | |
| F_27:28 | 0.42 | 0.525 | | | | | |
| F_29:30 | 3.59 | 0.018 | ** | | | | |

Sig. at 0.05

Insignificant

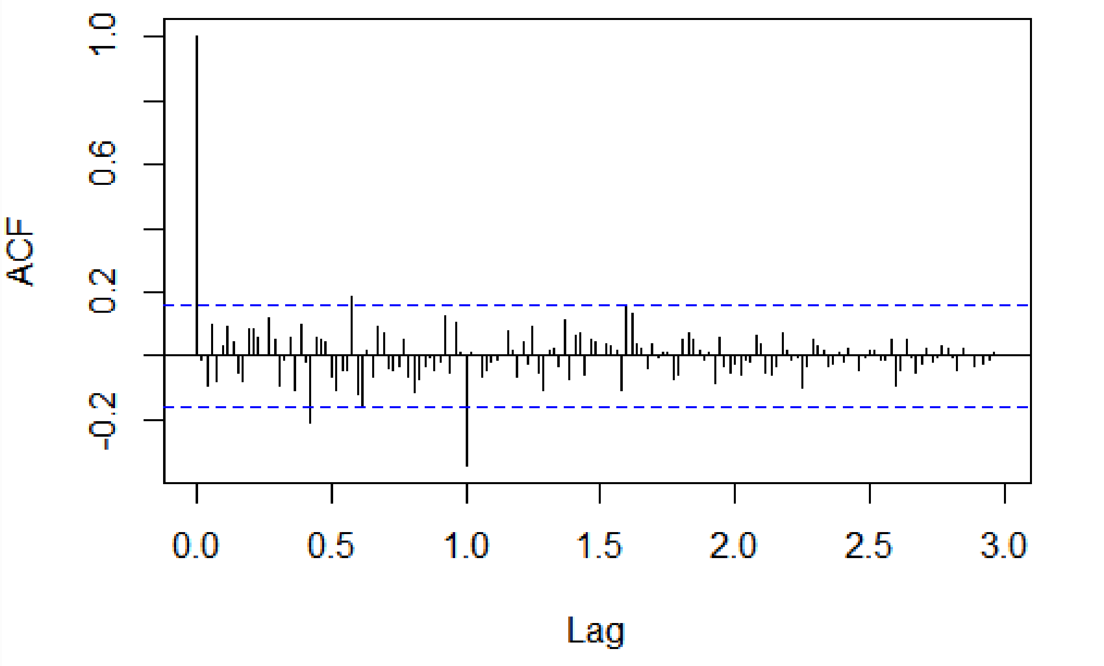
### HEGY Test Statistics on 1 Seasonal Diff.

| | test statistic | p-value | | | test statistic | p-value | |
|---|---|---|---|---|---|---|---|
| t_1 | -3.50 | 1.000 | | F_31:32 | 3.68 | 0.013 | ** |
| t_2 | -1.18 | 0.991 | | F_33:34 | 3.72 | 0.013 | ** |
| F_3:4 | 3.55 | 0.013 | ** | F_35:36 | 3.22 | 0.014 | ** |
| F_5:6 | 4.45 | 0.012 | ** | F_37:38 | 4.56 | 0.011 | ** |
| F_7:8 | 0.62 | 0.018 | ** | F_39:40 | 3.67 | 0.013 | ** |
| F_9:10 | 2.53 | 0.015 | ** | F_41:42 | 6.59 | 0.000 | *** |
| F_11:12 | 6.10 | 0.008 | ** | F_43:44 | 3.99 | 0.013 | ** |
| F_13:14 | 5.57 | 0.009 | ** | F_45:46 | 4.19 | 0.012 | ** |
| F_15:16 | 3.42 | 0.014 | ** | F_47:48 | 3.19 | 0.014 | ** |
| F_17:18 | 4.97 | 0.011 | ** | F_49:50 | 2.97 | 0.014 | ** |
| F_19:20 | 0.63 | 0.018 | ** | F_51:52 | 1.70 | 0.017 | ** |
| F_21:22 | 5.24 | 0.010 | ** | F_2:52 | 6.99 | 0.304 | |
| F_23:24 | 3.66 | 0.013 | ** | F_1:52 | 7.13 | 0.000 | *** |
| F_25:26 | 5.11 | 0.010 | ** | | | | |
| F_27:28 | 1.39 | 0.017 | ** | | | | |
| F_29:30 | 0.99 | 0.017 | ** | | | | |

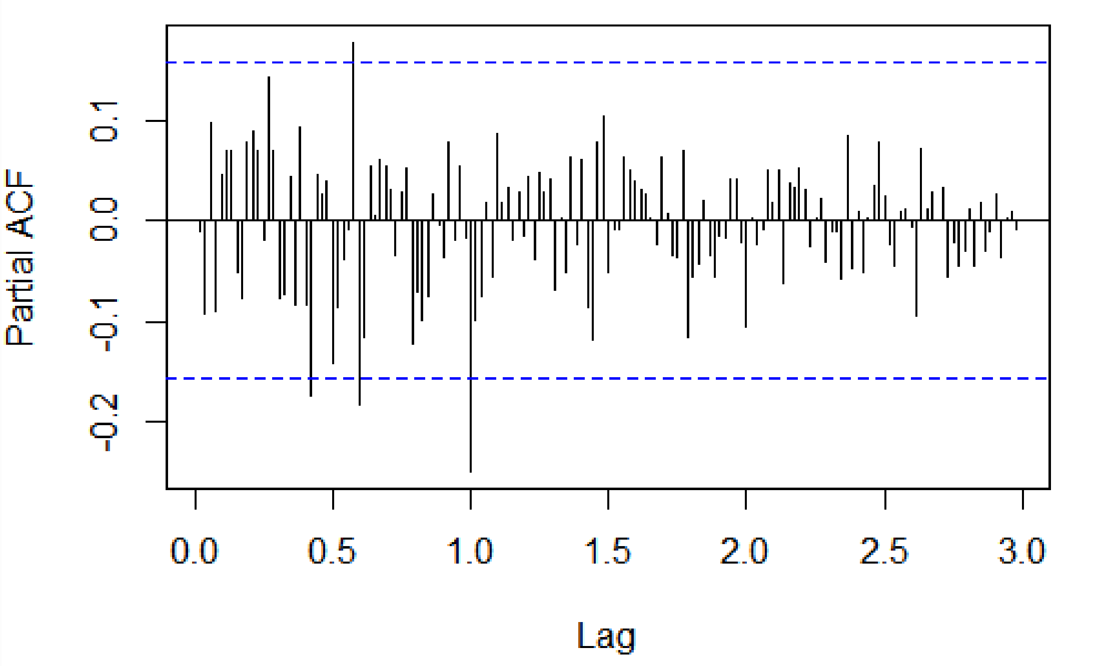
# Frequentist Approach: ARIMA Modeling

## HEGY statistics on 1 seasonally difference show no unit roots

### Seasonally Differenced ACF




### Seasonally Differenced PACF



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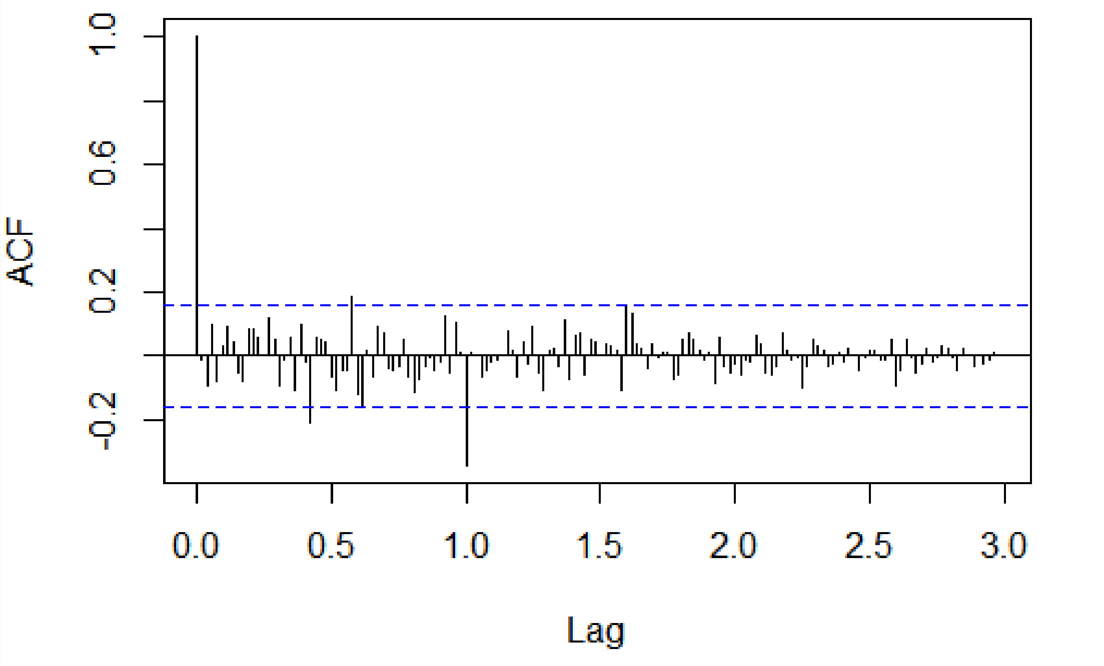


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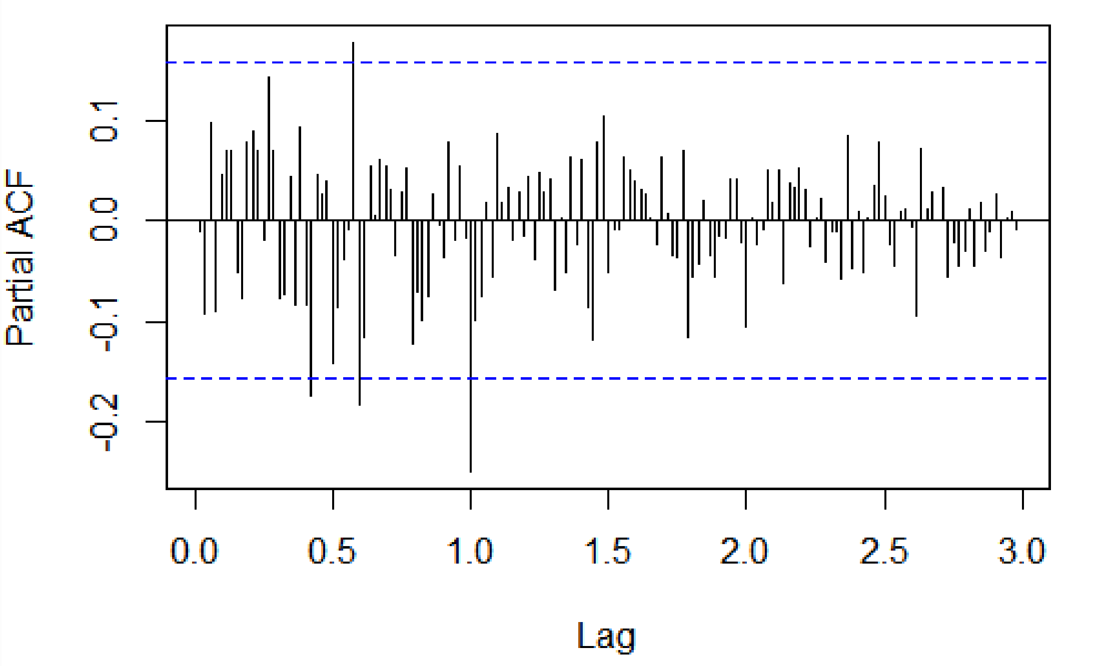



**Move forward with a SAR(1), SMA(1), pure noise models (of seasonal order 1)**

# Frequentist Approach: ARIMA Modeling

## SAR(1) is only model that passes coefficient quality checks.

| | SAR(1) | SMA(1) | Pure Noise | |
|---|---|---|---|---|
| Estimate (P-Value) | sar1: -0.49 (0.000)<br>treatment: -0.03 (0.449) | sma1: -0.99 (0.223)<br>treatment: -0.04 (0.421) | treatment: -0.04 (0.46) | Coefficient Quality |

**Ljung-Box Test

$H_o$: Independent errors -- White Noise

# Frequentist Approach: ARIMA Modeling

## SAR(1) and SMA(1) have lowest AIC and BIC.

| | SAR(1) | SMA(1) | Pure Noise | |
|---|---|---|---|---|
| Estimate (P-Value) | sar1: -0.49 (0.000)<br>treatment: -0.03 (0.449) | sma1: -0.99 (0.223)<br>treatment: -0.04 (0.421) | treatment: -0.04 (0.46) | Coefficient Quality |
| AIC | -60.87 | -0.71 | -0.31 | Model fit |
| BIC | -51.47 | -0.61 | -0.25 | |

**Ljung-Box Test

$H_o$: Independent errors -- White Noise

# Frequentist Approach: ARIMA Modeling

## SAR(1) and SMA(1) pass Ljung-Box Test.

| | SAR(1) | SMA(1) | Pure Noise | |
|---|---|---|---|---|
| Estimate (P-Value) | sar1: -0.49 (0.000)<br>treatment: -0.03 (0.449) | sma1: -0.99 (0.223)<br>treatment: -0.04 (0.421) | treatment: -0.04 (0.46) | Coefficient Quality |
| AIC | -60.87 | -0.71 | -0.31 | Model fit |
| BIC | -51.47 | -0.61 | -0.25 | |
| Ljung-Box Test | | | | Residual Quality |
| lag 5 p-value | 0.41 | 0.21 | 0.08 | |
| lag 10 p-value | 0.43 | 0.48 | 0.17 | |
| lag 15 p-value | 0.13 | 0.2 | 0.11 | |
| lag 20 p-value | 0.15 | 0.34 | 0.05 | |
| lag 25 p-value | 0.11 | 0.31 | 0.03 | |

**Ljung-Box Test

$H_o$: Independent errors -- White Noise

# Frequentist Approach: ARIMA Modeling

## Treatment variable shows no significant effect on collisions

| | SAR(1) |
| --- | --- |
| Estimate (P-Value) | sar1: **-0.49 (0.000)**<br>treatment: **-0.03 (0.449)** |

Conclusion: No significant impact of lowering the BAC on DUI related collisions

# Bayesian Approach: Model Comparison

## We compare 5 state-space models

**Model 1:** Local Linear Trend & Seasonality

**Model 2:** Seasonality only

**Model 3:** Local Linear Trend only

**Model 4:** Semi Local Linear Trend only

**Model 5:** Semi Local Linear Trend & Seasonality

Modeled using BSTS in R: https://www.rdocumentation.org/packages/bsts/versions/0.9.0

**Evaluation**

- RMSE on one-step-ahead predictions
- RMSE on a holdout
- $R^2$ & Harvey's GOF (random walk $R^2$)
- Posterior Predictive Checks

# Bayesian Approach: Model Comparison

## Models 4 & 5 lead other models across evaluation criteria

| | $R^2$ | HarveyGOF | RMSE (one-step) | RMSE (holdout) |
|---|---|---|---|---|
| Model 1 | 11.7% | 42.2% | 0.181 | 0.172 |
| Model 2 | 9.1% | 48.3% | 0.171 | 4.497 |
| Model 3 | -0.6% | 48.5% | 0.171 | 0.173 |
| Model 4 | 5.6% | 49.9% | 0.169 | 0.168 |
| Model 5 | 16.5% | 43.5% | 0.179 | 0.162 |

# Bayesian Approach: Model Comparison

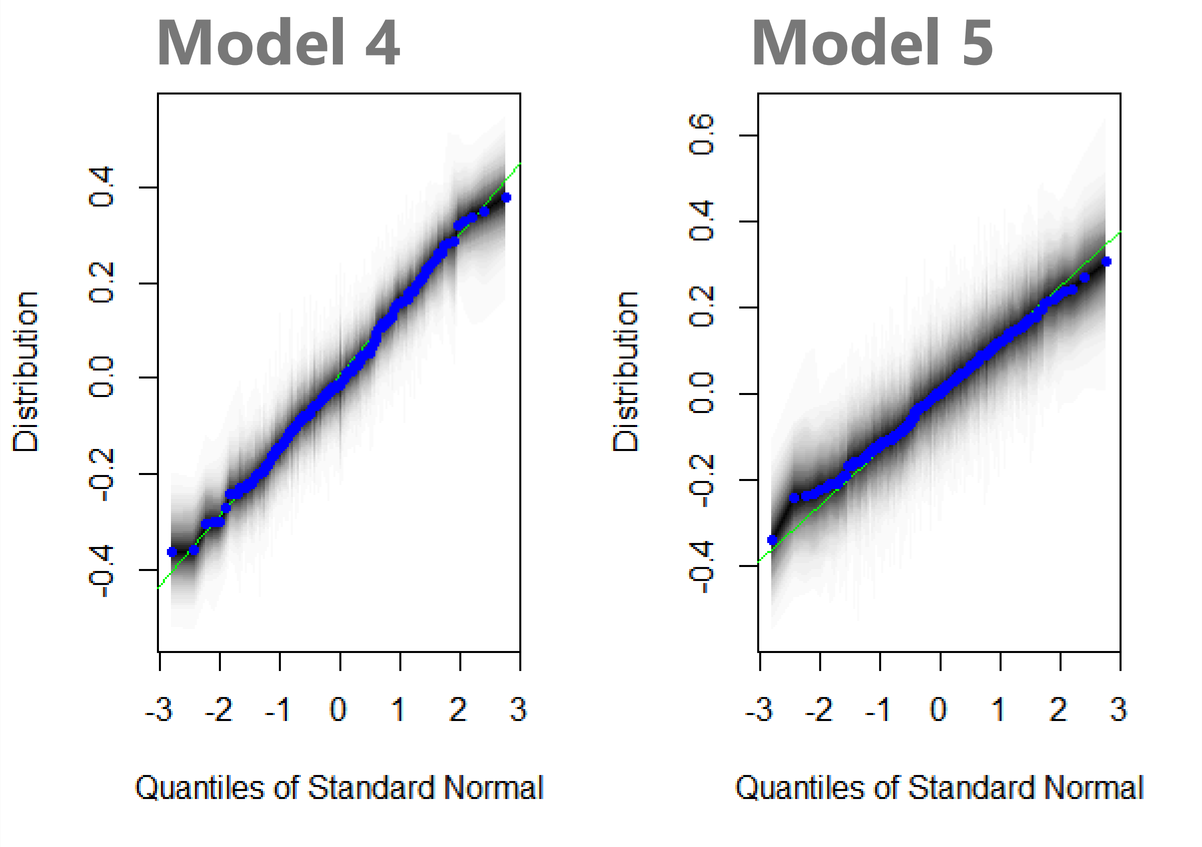
## Models 4 & 5 lead other models across evaluation criteria

| | $R^2$ | HarveyGOF | RMSE (one-step) | RMSE (holdout) | |
|---|---|---|---|---|---|
| Model 1 | 11.7% | 42.2% | 0.181 | 0.172 | |
| Model 2 | 9.1% | 48.3% | 0.171 | 4.497 | |
| Model 3 | -0.6% | 48.5% | 0.171 | 0.173 | |
| Model 4 | **5.6%** | **49.9%** | **0.169** | **0.168** | Semi Local Linear Trend |
| Model 5 | **16.5%** | **43.5%** | **0.179** | **0.162** | Semi Local Linear Trend & Seasonality |

# Bayesian Approach: PPC Residual Checks

## Q-Q plots show both model residuals are approx. normal

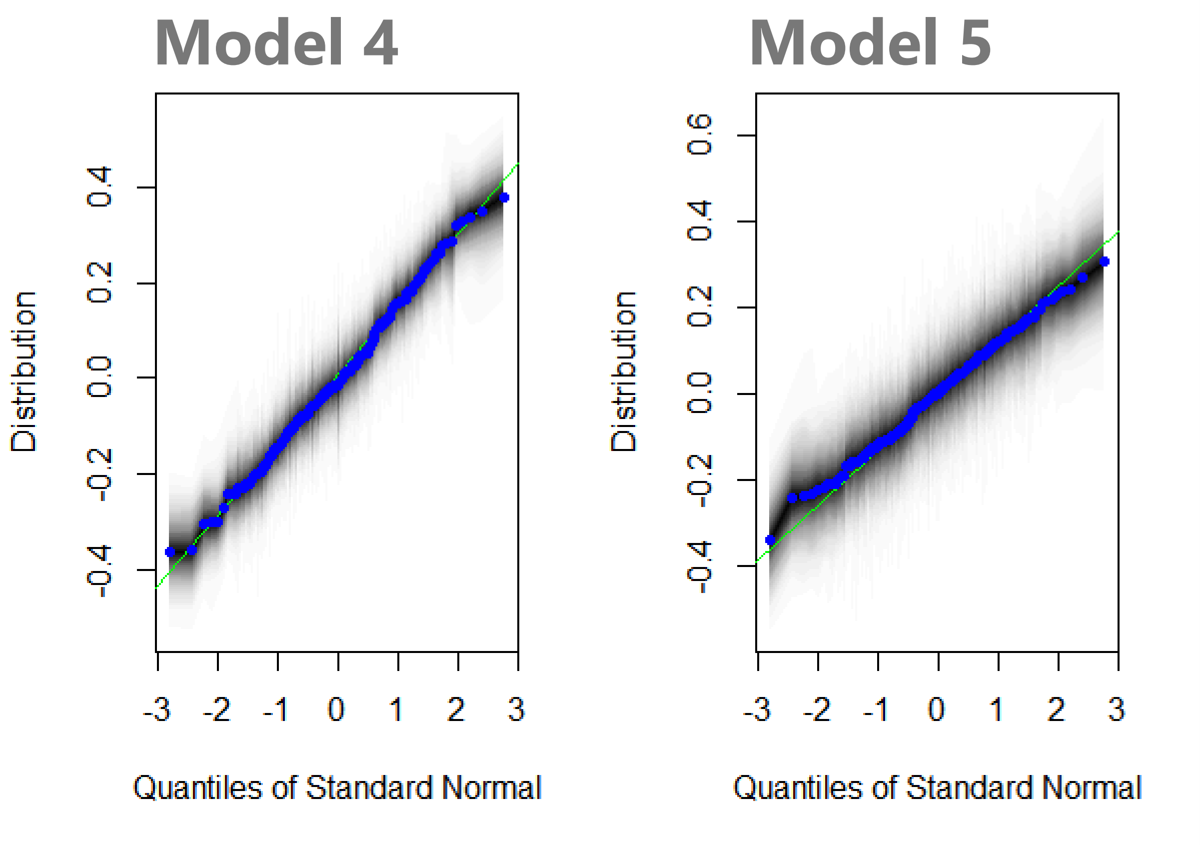
### Normal Q-Q Plots



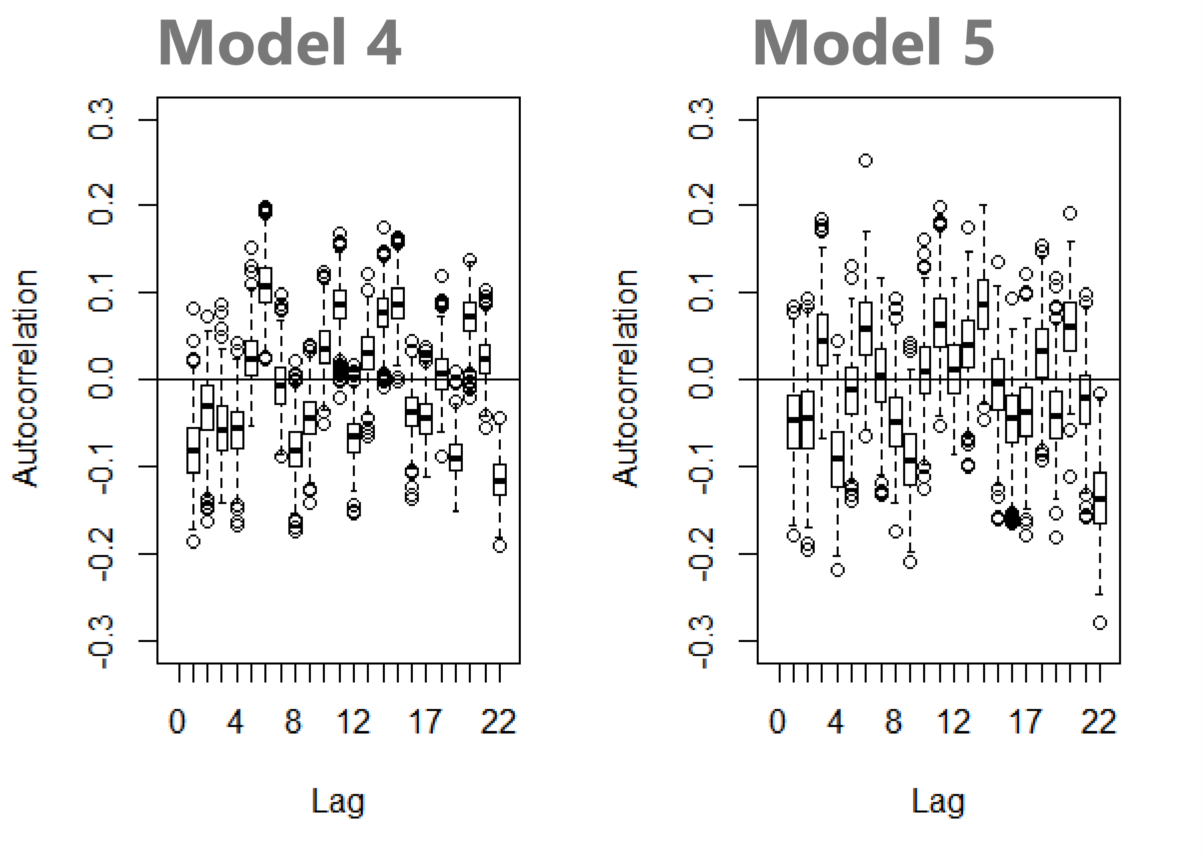
# Bayesian Approach: PPC Residual Checks

## Neither model has a problem with serial correlation.

### Normal Q-Q Plots



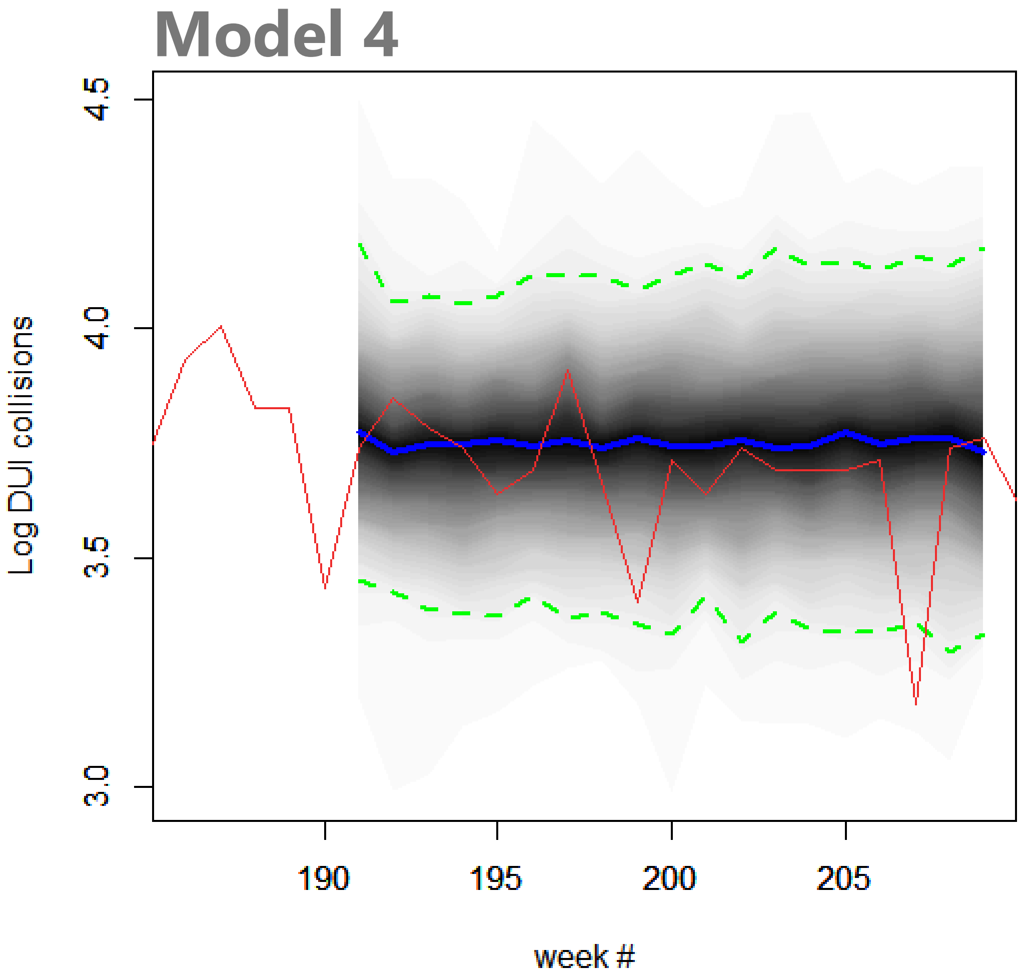

### Residual ACF

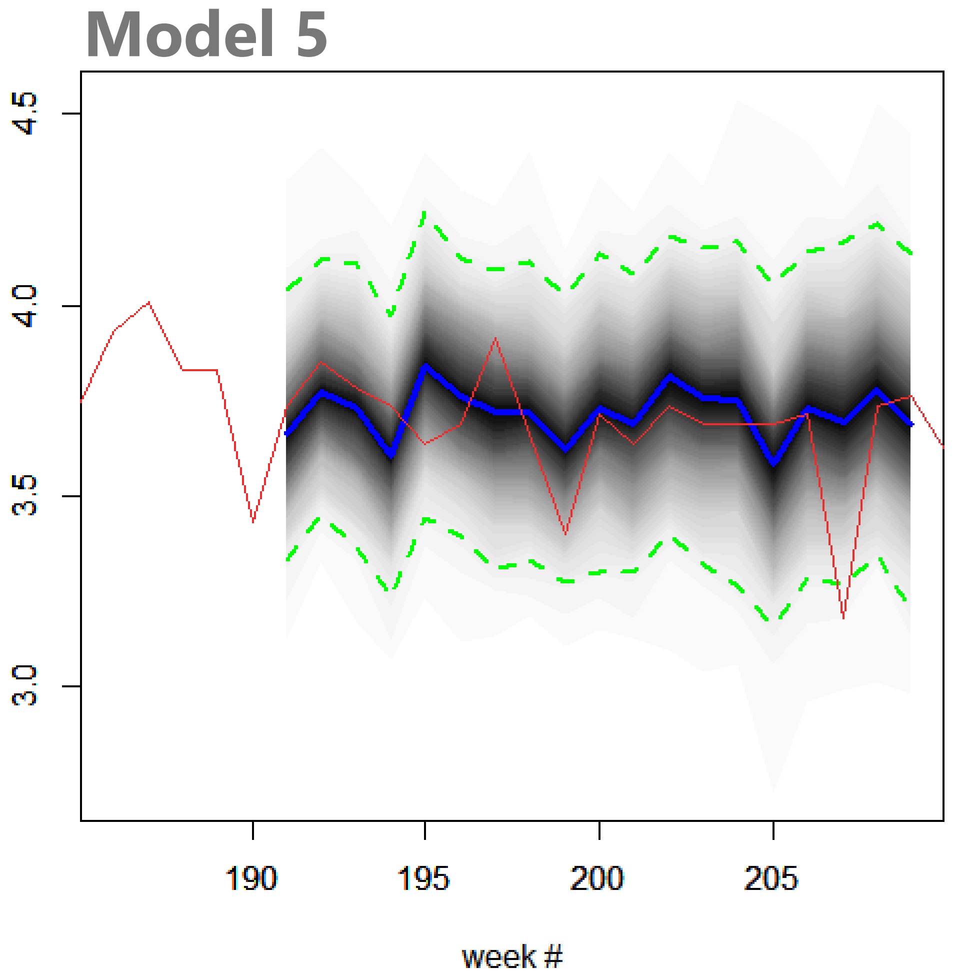


# Bayesian Approach: Graphical Predictive Checks

## Model 5 appears to move closely with observed data

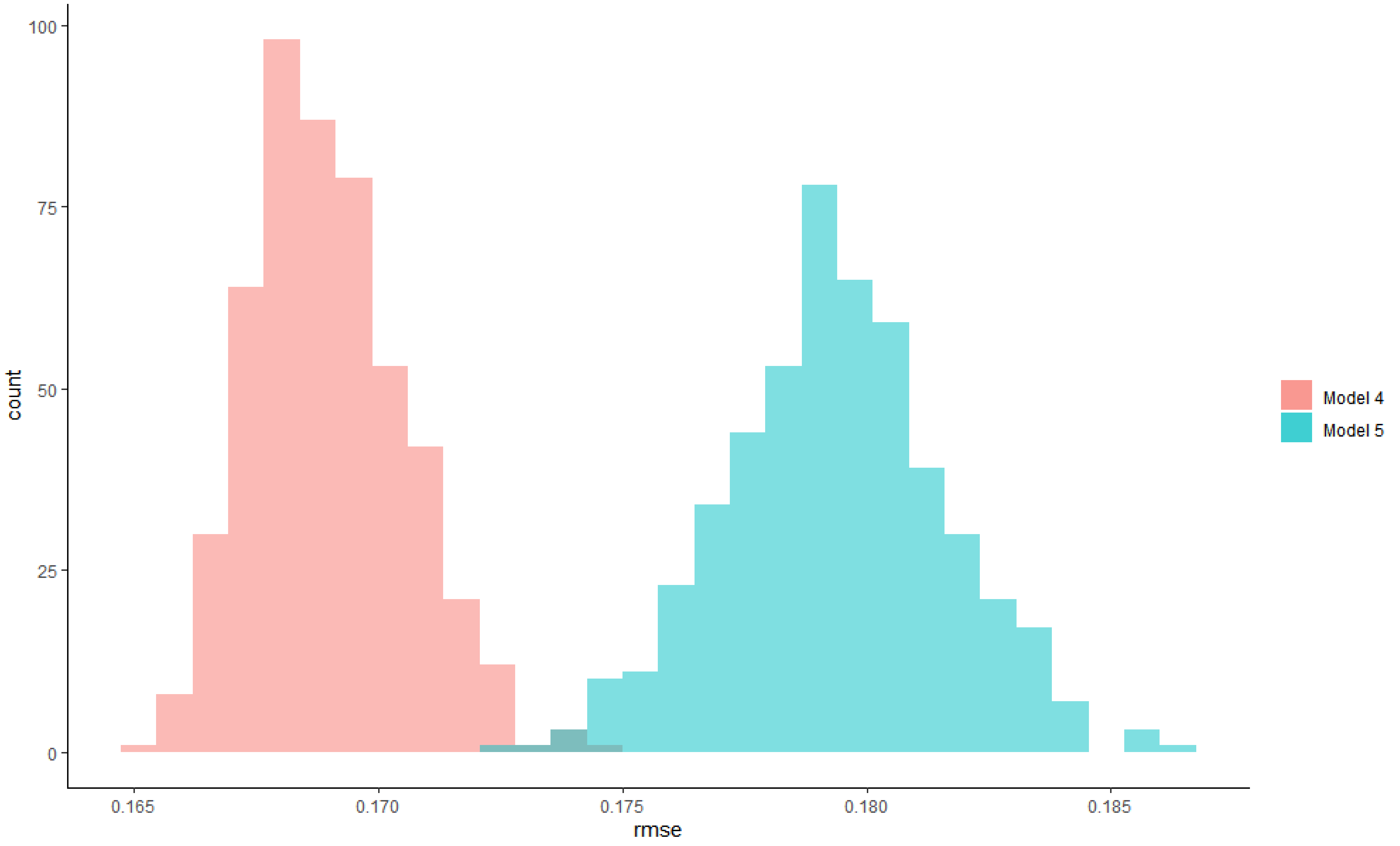
### Poster Predictions (20-step-ahead)



# Bayesian Approach: Graphical Predictive Checks

## Model 4 wins in terms of one-step-ahead RMSE



# Bayesian Approach: Treatment Evaluation

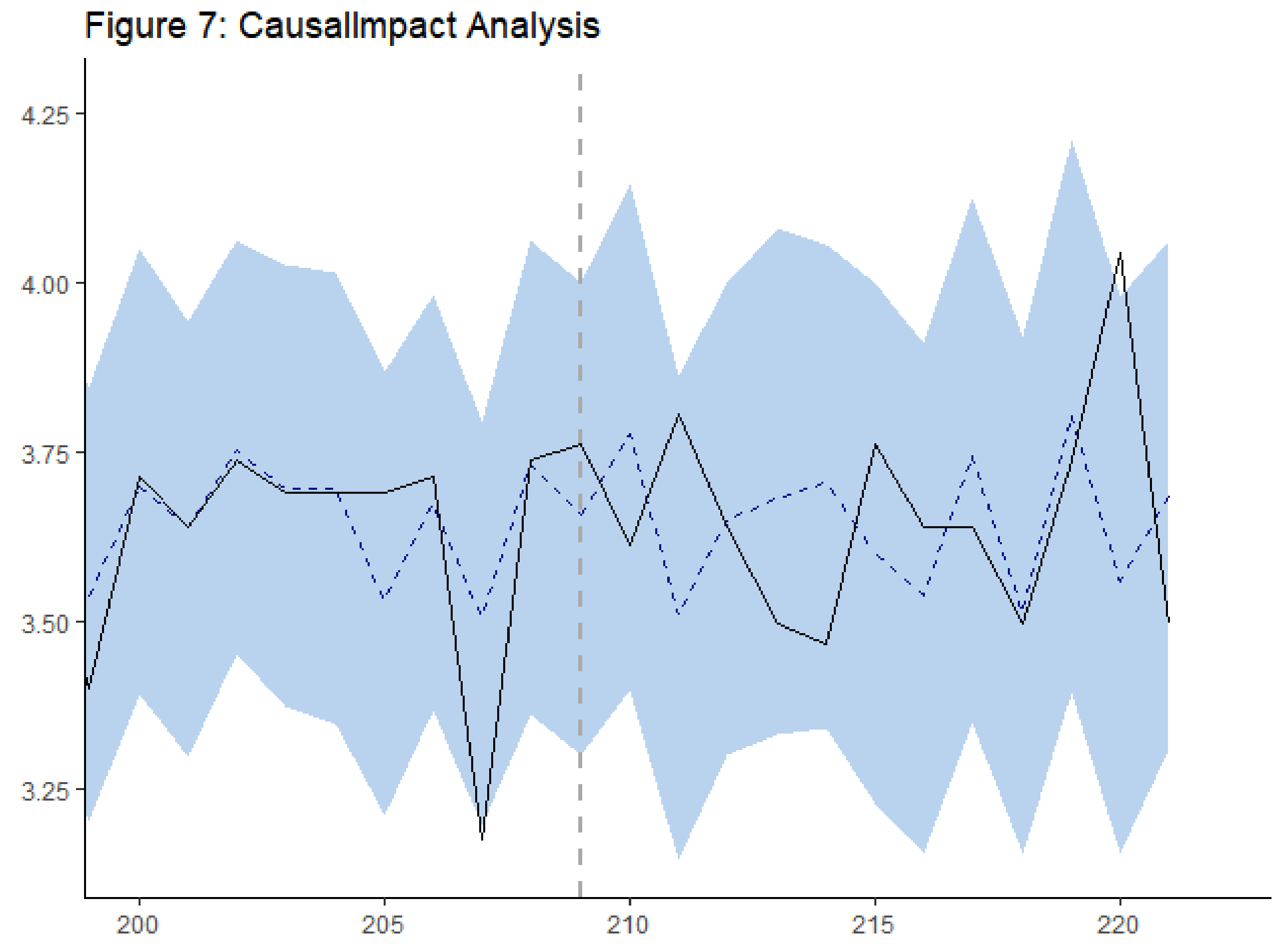
## Neither model shows a significant effect of a lower BAC

| | Inclusion Probability | Coefficient (95% HPD) |
|---|---|---|
| Model 4 | **1.4%** | **0.045 (-0.08, 0.17)** |
| Model 5 | **1.2%** | **0.036 (-0.18, 0.25)** |

- Both models show inclusion probability much lower than conventional 10% threshold
- 95% HPD for both models includes zero meaning we can’t determine a significant effect.

# Robustness Check

## Robustness check also shows zero effect of lower BAC.




Expected log DUI collisions: **3.65 (3.35, 3.96)**

Observed log DUI collisions: **3.65**

Effect size: **0.0001 (-0.3, 0.3)**

Built in state-space causal modeling using CausalImpact R package provides a robustness check to previous results. Note, this is an entirely different methodology using our same state-space Model 5.

# Conclusion

- **Results:**
  - **Both Frequentist and Bayesian methods show no significant impact**

- **Limitations:**
  - **DUI related deaths is what most previous research has studied**

  - **It’s customary to normalize by vehicle miles driven.**

  - **Data only includes up to the first quarter of 2019**