

# **Report on Bayesian Hierarchical Model Analysis of Insurance Charges**

## **1. Overview**

This analysis investigates the factors influencing insurance charges using a Bayesian hierarchical model. The data includes variables such as age, sex, BMI, number of children, smoking status, and region. Interaction terms were considered to capture the combined effects of these variables.

## **2. Data Preprocessing**

Data Cleaning and Preprocessing:

Outliers Removal: Outliers were removed based on the IQR method for variables such as charges, age, BMI, and children.

Encoding:

Categorical variables (sex and smoker) were binary encoded.

Regions were one-hot encoded.

Interaction Terms: Interaction terms were created to capture combined effects, e.g., age with smoker, BMI with smoker, etc.

## **3. Bayesian Hierarchical Model**

The model formula allows for varying intercepts across different regions, capturing regional variations in insurance charges.

## **4. Model Summary**

Multilevel Hyperparameters:

sd(Intercept) for Regions: Indicates variability in charges across regions.

Region-wise Standard Deviations: Suggest notable differences with high uncertainty (large credible intervals).

Regression Coefficients:

Age: Positively associated with charges.

Sex: Negative coefficient indicates lower charges for females.

BMI: Positively associated with charges.

Children: More children correlate with higher charges.

Smoker: Smoking has a significant negative coefficient when isolated, suggesting potential data anomalies.

Interaction Terms:

bmi\_smoker\_interaction and age\_smoker\_interaction: Show significant interaction effects.

Regional Interactions: Generally showed less significance but still contributed to the model.

Performance Metrics:

MAE: 2469.559

MSE: 19249787

RMSE: 4387.458

R-squared: 0.6349453

## **5. Region-wise Trends**

Variability in Charges: Different sd(Intercept) values for each region indicate variability.

Model's Capture: The model captures regional variability with considerable uncertainty (wide credible intervals).

## **6. Significant Covariates**

Age and BMI: Consistently significant predictors of charges.

Smoking Status: Has a complex effect, particularly in interaction terms.

Number of Children: Positively impacts charges.

Interactions: Significant interactions include bmi\_smoker\_interaction and age\_smoker\_interaction, indicating that the impact of BMI and age varies based on smoking status.

## **7. Bayesian Prediction Utility**

Uncertainty Quantification: Bayesian methods provide credible intervals for predictions, offering a range of possible outcomes rather than a single point estimate.

Handling Complex Models: Bayesian hierarchical models manage complex structures like multilevel data effectively.

Parameter Interpretation: Bayesian estimates (posterior distributions) offer a more intuitive interpretation with direct probability statements.

## **8. Regional Variations in Insurance Charges**

Regional Differences:

Northwest: Lower insurance charges compared to the Northeast.

Southeast and Southwest: Higher insurance costs compared to the Northeast.

Region with Lowest Insurance Charges:

Northwest Region: Among the regions analyzed, the Northwest is associated with the lowest insurance charges compared to the Northeast.

## **9. Impact of Age on Insurance Charges**

Positive Association: Older individuals tend to incur higher insurance costs.

Optimal Age Group: Younger individuals, particularly those in their 20s and 30s, face lower insurance charges.

## **10. Influence of Smoking Status on Insurance Charges**

Higher Costs for Smokers: Smoking status significantly impacts insurance charges, with smokers generally facing higher costs.

Non-Smokers: Associated with lower insurance charges.

## **11. Effect of BMI on Insurance Charges**

Positive Correlation: Higher BMI levels are linked to increased costs.

Optimal BMI Range: Individuals within the normal BMI range (18.5-24.9) are likely to incur lower insurance charges.

## **12. Impact of the Number of Children on Insurance Charges**

Increase with Number of Children: Insurance charges tend to increase with the number of children.

Optimal Family Size: Individuals with fewer or no children face lower insurance charges.

## **13. Insights from Interaction Terms**

Age-Smoker Interaction: The increase in insurance charges due to aging is more pronounced for smokers.

BMI-Smoker Interaction: The effect of BMI on charges is significantly higher for smokers compared to non-smokers.

Age-BMI-Smoker Interaction: The combined impact of aging, high BMI, and smoking status results in substantially higher insurance charges.

These interactions emphasize the importance of considering multiple factors together to understand their joint influence on insurance costs.

## **Conclusion**

The Bayesian hierarchical model provides valuable insights into the factors affecting insurance charges. While the model captures significant predictors and their interactions effectively, attention to model diagnostics and potential refinement is essential for robust inference.

The optimal profile for minimum insurance charges includes individuals residing in the Northwest, in their 20s or 30s, non-smokers, with a normal BMI range (18.5-24.9), and with fewer or no children.