Exploring Determinants of Child Mortality (2022): The Role of Vaccination, Healthcare Spending, and Nutrition figure, no histogram/scatterplot of*

Findings Reveal Vaccination and Healthcare Spending as Key Drivers of Mortality Reduction

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Child mortality has significantly decreased over the past three decades, but progress remains uneven across regions. This study examines the under-five mortality rates of 2022, focusing on the effects of vaccination coverage, health expenditure per capita, and food production indices. Using a Bayesian modeling approach, we found that increased vaccination coverage and healthcare spending significantly reduce child mortality, while food production had no direct impact. These findings underscore the critical need for targeted interventions in high-mortality regions, emphasizing the importance of vaccination programs and healthcare funding in achieving global child survival goals.

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*Code and data are available at: [https://github.com/Junbo345/Mortality_analysis].

1 Introduction

Over the past 30 years, advancements in society and technology have significantly reduced global mortality rates, particularly for children under the age of five. The under-five mortality rate declined from 93 deaths per 1,000 live births in 1990 to 37 deaths per 1,000 live births in 2022 (Arel-Bundock 2022). This progress represents millions of children who now have better chances of survival, marking a substantial achievement in global health.

In this study, we examined the under-five mortality rate for each country in 2022, focusing on three key factors: food production index, DPT vaccine coverage, and per-capita health expenditure. These factors were chosen because they reflect critical components influencing child mortality. Infectious diseases, such as pneumonia, diarrhea, and malaria, remain leading causes of under-five deaths, and these are directly linked to vaccination coverage and healthcare spending. Similarly, maternal health during childbirth is influenced by healthcare accessibility and quality, which is often tied to national health expenditures (World Health Organization 2024). While food production does not directly address infectious disease or maternal health, it reflects a nation's ability to meet nutritional needs, which is critical for preventing malnutrition—a major underlying cause of child deaths (add supporting explanation and citation).

Our findings reveal that increasing vaccine coverage and per-capita health expenditures significantly reduces under-five mortality rates. However, food production index does not exhibit a direct impact, suggesting that its role is mediated by other factors such as distribution systems and food quality. Despite progress in reducing global mortality, the pace of reduction has slowed considerably since 2015, decreasing from an annual rate of 3.8% during the Millennium Development Goal (MDG) era (2000–2015) to 2.1% during the Sustainable Development Goal (SDG) era (2015–2022) (UNICEF 2022). In 2022 alone, 4.9 million children under the age of five died, equating to approximately 13,400 deaths per day (UNICEF 2022).

Furthermore, the distribution of under-five mortality rates remains highly uneven. Developed countries such as Canada and the United States report mortality rates as low as 10 per 1,000 live births, while developing nations—particularly in sub-Saharan Africa—experience rates exceeding 100 per 1,000 live births (Arel-Bundock (2022)). This disparity highlights the urgent need for targeted interventions in high-mortality regions. The factors studied in this paper, such as vaccination and healthcare spending, are actionable and can be effectively improved in these regions through foreign aid and international collaboration.

The remainder of this paper is organized as follows. Section 2 describes the data sources, key variables, and preprocessing steps, including transformations applied to address skewness and improve model validity. Section 3 outlines the modeling approach, including the choice of predictors, justification of the model structure, and Bayesian implementation. Section 4 presents the results of the analysis, highlighting the effects of each predictor on under-five mortality. Finally, Section 5 discusses the implications of the findings, the limitations of the study, and recommendations for future research and policy interventions aimed at reducing child mortality globally.

1.1 Estimand

The primary estimand of this study is the effect of three predictors—food production index, vaccination coverage (DPT vaccine percentage), and per-capita health expenditure (log-transformed)—on the logarithm of the under-five mortality rate for each country in 2022. This analysis seeks to quantify the extent to which these factors contribute to variations in mortality rates across nations. By addressing these relationships, the study aims to identify potential intervention points for reducing preventable child deaths and achieving progress toward the Sustainable Development Goals for child survival.

2 Data

2.1 Overview Check packages

For this analysis, we combined four data sets all together into one. All these four data sets comes from **Worldbank** open data platform (Arel-Bundock 2022). We employed **R** (R Core Team 2023), a coding platform to download, clean and conduct statistical analysis. Besides, we also utilized R packages **tidyverse** (Wickham et al. 2019), **rstanarm** (Goodrich et al. 2022), **ggplot2** (Wickham 2016), **knitr** (Xie 2014), **arrow** (Richardson et al. 2024), **here** (Müller 2020), and **dpylr** (Wickham et al. 2023). The paper is outlined in github using starter folder provided in **Telling Stories With Data** (Alexander 2023).

2.2 Measurement

The analysis in this study relies on four data sets, each collected and prepared by various UN-affiliated organizations. Below, we provide a brief overview of the measurement and transformation processes for these data sets. Detailed descriptions and methodological specifics can be found in Section A.

2.2.1 Response variable:

Mortality Rate: The child mortality rate is estimated by the UN Inter-agency Group for Child Mortality Estimation (IGME). The primary data source is each country's vital registration system. These raw data are then processed using a statistical model developed collaboratively by UN agencies and academic institutions to derive robust mortality rate estimates (World Bank 2024d).

2.2.2 Predictors:

Food Production Index: This index, prepared by the Food and Agriculture Organization (FAO) of the United Nations, measures aggregate food production relative to the 2014–2016 baseline period. It is calculated using price-weighted data on agricultural products for each country on an annual basis (World Bank 2024b).

Health Expenditure per Capita: Data on health expenditure per capita are produced by the World Health Organization (WHO) following the System of Health Accounts 2011 (SHA

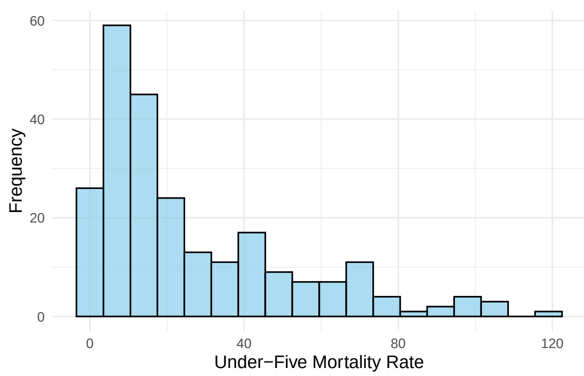
2011) framework. This framework tracks all health-related spending in a country over a defined time period (World Bank 2024a).

DPT Vaccine Coverage: DPT vaccine coverage is jointly estimated by the WHO and UNICEF. This metric reflects the percentage of children aged 12–23 months in each country who have received the diphtheria, pertussis (whooping cough), and tetanus (DPT) vaccine. Estimates are derived from reports by vaccine service providers and household surveys of vaccination history (World Bank 2024c).

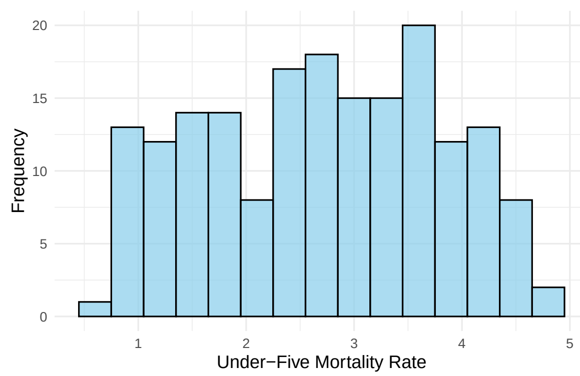
2.3 Outcome variables

The response variable in this study is the under-five mortality rate, measured as the number of deaths of children under five years old per 1,000 live births.

The untransformed data range from 0 to 120, with a peak between 10 and 15 deaths per 1,000 live births (Figure 1a). Due to the presence of extreme values and significant right skewness, a log transformation was applied to stabilize variance and improve normality. The transformed data range from 2 to 5, with a peak near 3 (Figure 1b).



(a) Dsitribution before log tranformation



(b) Distribution after log transformation

Figure 1: Data Analysis for Mortality Rate of Different Countries

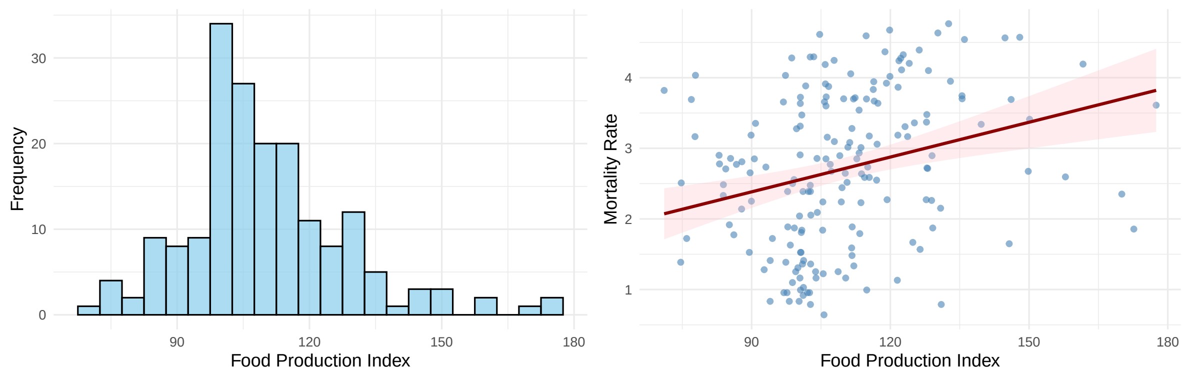
2.4 Predictor variables

The three predictors analyzed are:

Food Production Index: The Food Production Index measures the relative level of agricultural production for each country compared to the 2014–2016 baseline (Arel-Bundock 2022). This index reflects price-weighted data of agricultural products for each country.

Distribution: As shown in Figure 2a, the index ranges from 60 to 180, with a center around 110 and an approximately normal distribution.

Relationship with Mortality: Scatter plot analysis (Figure 2b) reveals a slightly positive linear relationship between food production and the log-transformed mortality rate, with a fitted line and confidence intervals. This relationship will be explored in greater detail in Section 3.



(a) Counts of Food production index for each country, measured as a basis of 2014-1016

(b) Relationship of each countries' Food production index VS. Log of Mortality rate

Figure 2: Data Analysis of Predictor Food Production Index

Current Health Expenditure: The Current Health Expenditure per Capita (measured in USD) reflects each country's health spending, collected using the System of Health Accounts (SHA 2011) framework.

Distribution: The raw data ranges from \$0 to \$12,000, as shown in Figure 3a. Due to extreme right skewness, we applied a log transformation to normalize the distribution, resulting in a range of 0 to 10, with a center at 6 (Figure 3b).

Relationship with Mortality: As illustrated in Figure 3c, a significant negative linear relationship exists between log-transformed health expenditure and log mortality rate. Further analysis is detailed in Section 3.

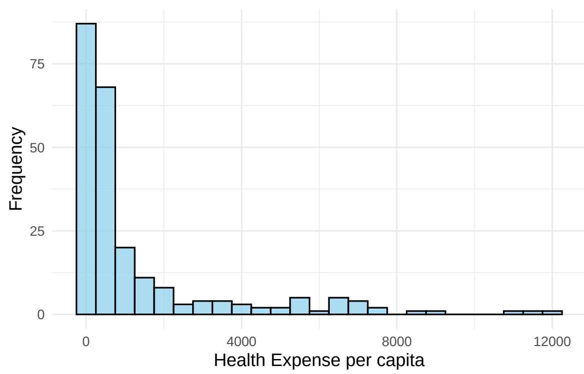
DPT Vaccine Coverage The DPT Vaccine Coverage measures the percentage of children aged 12–23 months who received vaccinations for diphtheria, pertussis, and tetanus.

Distribution: As shown in Figure 4a, coverage ranges from 30% to 100%, with a left-skewed distribution.

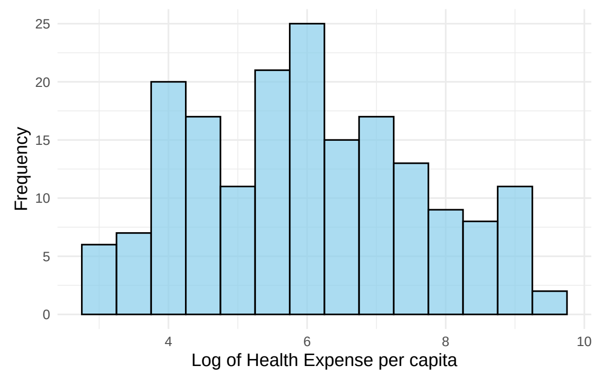
Relationship with Mortality: A significant negative association is observed in Figure 4b. This relationship will be analyzed further in Section 3.

2.5 Missing Data and Time Inconsistancy

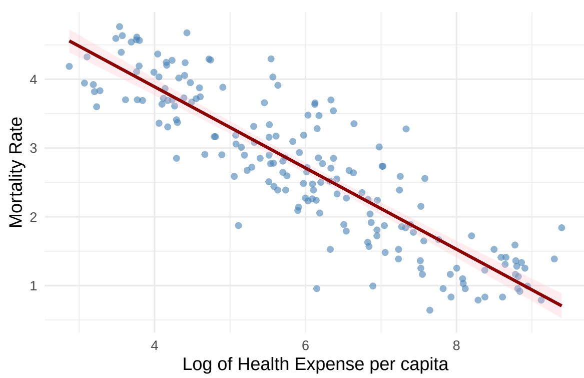
The health expenditure variable was collected in 2021, while other variables reflect 2022 data. This discrepancy is due to unavailability of more recent health expenditure data. These 2021 values are assumed to approximate 2022 conditions sufficiently for analysis.



(a) Counts of each countries' Health Expenditure Per Capita, Measured in US$. Before log transformation

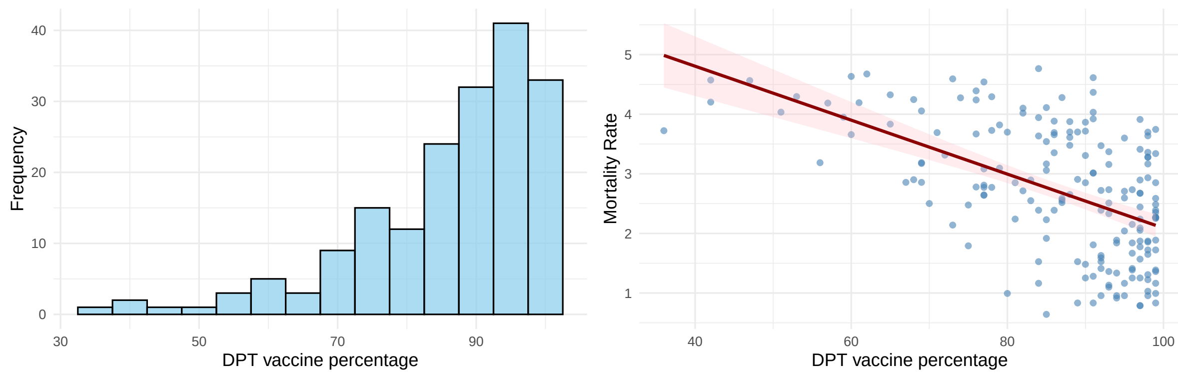


(b) Counts of each countries' Health Expenditure Per Capita, Measured in US$. After log transformation



(c) Relationship of each countries' Health Expenditure Per Capita, Measured in US$ VS. Log of Mortality

Figure 3: Data Analysis of Predictor Current Health Expenditure



(a) Counts of each countries' DPT vaccine percentage

(b) Relationship of each countries' DPT Vaccine Percentage VS. Log of Mortality

Figure 4: Data Analysis of Predictor DPT Vaccine Percentage

Additionally, some smaller countries lacked complete data and were excluded from the analysis. The implications of these omissions are addressed in Section 4.

3 Model

TOur modeling strategy aims to explore the relationships between DPT vaccine coverage, the food production index, and current health expenditure per capita (in current US$) with the under-five mortality rate across nations. By analyzing these factors, we seek to identify opportunities to improve child health outcomes, particularly in countries with high mortality rates. Supporting background information and diagnostics are provided in Appendix B.

3.1 Model set-up

Let y_i be the logarithm of under-five mortality rate for nation i. We define the following predictors:

x_{1i}: DDT vaccine coverage for nation i. x_{2i}: Food production index for nation i. x_{3i}: Logarithm of current health expenditure per capita (current US$) for nation i. The model is specified as:

$$
\begin{aligned}
y_i \mid \mu_i, \sigma &\sim \text{Normal}(\mu_i, \sigma) && (1)\\
u_i &= \alpha + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} && (2)\\
\alpha &\sim \text{Normal}(2.5, 1) && (3)\\
\beta_1 &\sim \text{Normal}(0, 2.5) && (4)\\
\beta_2 &\sim \text{Normal}(0, 2.5) && (5)\\
\beta_3 &\sim \text{Normal}(0, 2.5) && (6)\\
\sigma &\sim \text{Exponential}(1) && (7)
\end{aligned}
$$

We implement this model in R (R Core Team 2023) using the rstanarm package (Goodrich et al. 2022).

3.1.1 Model justification

A multivariate linear model was chosen to capture the relationships between the predictors (DPT vaccine coverage, food production index, and current health expenditure) and the response variable (under-five mortality rate). This choice is supported by observed linear trends in the data (see Section 2). Logarithmic transformations were applied to both the under-five mortality rate and current health expenditure per capita to normalize the distributions and stabilize their linear relationships with the predictors.

Default Bayesian priors were used for the predictors, as they provide a robust starting point. For the intercept term, a Normal(2.5, 1) prior was chosen, reflecting the observed distribution of the response variable (see Section 2).

3.1.2 Model weakness

Several limitations are noted in this model:

1. Skewed Predictor Distribution: The distribution of DPT vaccine coverage is skewed left, which may introduce bias. Despite attempts to address this, an ideal solution remains elusive.
2. Potential Collinearity: While each predictor shows an individual linear relationship with the response variable, interdependencies between predictors may affect model accuracy.
3. Simplified Assumptions: The model assumes linearity and does not capture potential non-linear interactions or regional variations that could influence under-five mortality rates.

4 Results

Our results are summarized in Table 1.

4.1 Intercept:

The intercept estimate of 6.643 represents the expected logarithm of the under-five mortality rate when all predictors are held constant at their reference or baseline values (e.g., average food production, average vaccine coverage, and average health expenditure). This serves as a baseline for interpreting the effects of the predictors.

4.2 Food Production Index:

The coefficient for the food production index is 0.003, indicating a very slight positive relationship between food production and the under-five mortality rate. This naively suggests that reducing food production could also reduce mortality, which is counter-intuitive.

However, a closer examination of the confidence interval for this predictor shows that it includes 0. This implies that the relationship is not statistically significant, and food production is not strongly related to overall under-five mortality rates. This finding suggests that while food production is essential for societal well-being, its immediate impact on reducing child mortality might depend on other factors such as food access, distribution systems, and nutritional quality.

4.3 Vaccine Coverage:

The coefficient for vaccine coverage is -0.013, meaning that for every 1 percentage point increase in vaccine coverage, the logarithm of the under-five mortality rate decreases by 1.3%, holding other variables constant.

This highlights the critical role of vaccination programs in reducing child mortality. For example, increasing vaccine coverage by 10 percentage points could reduce the mortality rate by approximately 13%, emphasizing the importance of robust immunization initiatives.

4.4 Health Expenditure (Log-Transformed):

The coefficient for the log-transformed health expenditure is -0.529, indicating that a 1% increase in health expenditure per capita is associated with a 0.529 unit decrease in the log of the under-five mortality rate, holding all other predictors constant.

Table 1: Outcome predictors of our model

Term	Estimate	Std. Error	2.5% CI	97.5% CI
(Intercept)	6.641	0.350	6.048	7.224
Food	0.003	0.002	0.000	0.007
Vacinne	-0.013	0.003	-0.018	-0.008
Health_expense	-0.529	0.027	-0.573	-0.486

5 Discussion

5.1 implications

The UN's Sustainable Development Goal 3.2 aims to reduce the mortality rate of children under five to fewer than 25 per 1,000 live births by 2030 (World Health Organization n.d.). While substantial progress has been made, achieving this target within the next six years presents significant challenges. This study confirms that while the global trend shows a decrease, the pace of this reduction has slowed since 2015. Furthermore, in Section 2 we found significant disparities between countries. Some nations already meet the SDG target, but others exhibit mortality rates four times higher than the threshold, predominantly in low-income regions such as sub-Saharan Africa.

To meet the SDG targets, urgent and focused international collaboration is required. Our findings emphasize two critical areas for intervention: vaccine coverage and healthcare spending. Vaccination programs have a clear and significant impact on reducing child mortality. Therefore, international aid should prioritize making newborn vaccines affordable, ensuring their availability, and facilitating universal access in high-mortality regions.

Healthcare spending presents a more complex challenge. It encompasses multiple factors, including a country's economic status, infrastructure development, and access to hospital services. Addressing these requires a sustained, long-term commitment. Developed countries can play a pivotal role by providing financial support, sharing technological advancements, and fostering knowledge transfer to enhance healthcare systems in developing nations. Without addressing these systemic issues, achieving equitable child survival rates will remain elusive.

5.2 limitation and next steps

This study has several limitations that should be addressed in future research. First, as discussed in Section 2, we lack data from several smaller countries. While their populations are minimal, excluding these nations raises potential biases and ethical concerns by not representing their unique challenges. Second, the most recent data available is from 2022. More current datasets would enable a more accurate analysis, reflecting recent developments in healthcare and child mortality trends.

Additionally, while this study focused on three predictors, the dataset contains other indicators that could potentially enrich the analysis. However, many of these indicators suffer from missing or outdated data, limiting their utility. Future research should prioritize ensuring data completeness and timeliness to enhance model robustness.

Lastly, advanced modeling techniques and the incorporation of additional predictors could yield deeper insights. Future studies should explore innovative models to capture complex relationships and interactions, thereby providing more nuanced recommendations for policy interventions.

Appendix

A Additional data details

A.1 Challenges in Observational Data and Sampling

The data used in this study, particularly under-five mortality rates, are largely derived from surveys, censuses, and observational data rather than complete vital registration systems. Observational data present unique challenges, such as recall bias in surveys, underreporting in regions with weak administrative systems, and inconsistencies in data collection methodologies across countries. These issues are particularly acute in low- and middle-income countries (LMICs), where infrastructure limitations impede accurate data capture.

Sampling Strategies To mitigate these challenges, the UN Inter-agency Group for Child Mortality Estimation employs a combination of direct and indirect estimation techniques. Direct methods rely on household surveys, such as Demographic and Health Surveys (DHS) and Multiple Indicator Cluster Surveys (MICS), which use stratified random sampling to ensure representativeness. These surveys ask respondents to recall birth and death histories, which introduces recall bias, particularly for events occurring further in the past.

Indirect methods use model life tables and historical data to extrapolate mortality estimates in the absence of recent or reliable survey data. These methods rely on assumptions about fertility, mortality trends, and the demographic structure of the population, which may not hold true in all contexts, particularly in regions experiencing rapid epidemiological transitions or conflict.

A.2 Linkages to Literature

The challenges and methodologies described align with findings in the literature. Alkema and New (2014) emphasized the importance of integrating multiple data sources to improve the reliability of child mortality estimates. They highlighted the use of Bayesian hierarchical models to synthesize survey and vital registration data, which is a key component of the UN Inter-agency Group's methodology.

Moultrie et al. (2013) detailed the limitations of indirect estimation methods, particularly their reliance on model assumptions that may not hold in regions undergoing rapid social or economic change. Their findings support the use of simulation studies, such as ours, to assess the robustness of mortality estimates under varying data quality scenarios.

A.3 Implications for Policy and Future Research

The limitations of survey-based and observational data highlight the need for:

Investment in Vital Registration Systems: Increasing the coverage and quality of birth and death registrations in LMICs would reduce reliance on indirect methods and improve the accuracy of mortality estimates. Improved Survey Methodologies: Incorporating digital data collection tools and cross-validation with other data sources can reduce recall bias and enhance data reliability. Advanced Statistical Techniques: Bayesian hierarchical models and machine learning approaches can integrate diverse data sources and account for biases more effectively than traditional methods. Future research should focus on combining survey data with novel data sources, such as satellite imagery and mobile health records, to address data gaps and improve mortality estimation in real time. These approaches could revolutionize the monitoring of global health indicators, enabling more targeted and timely interventions. (Add refer)

B Model details

B.1 Posterior predictive check

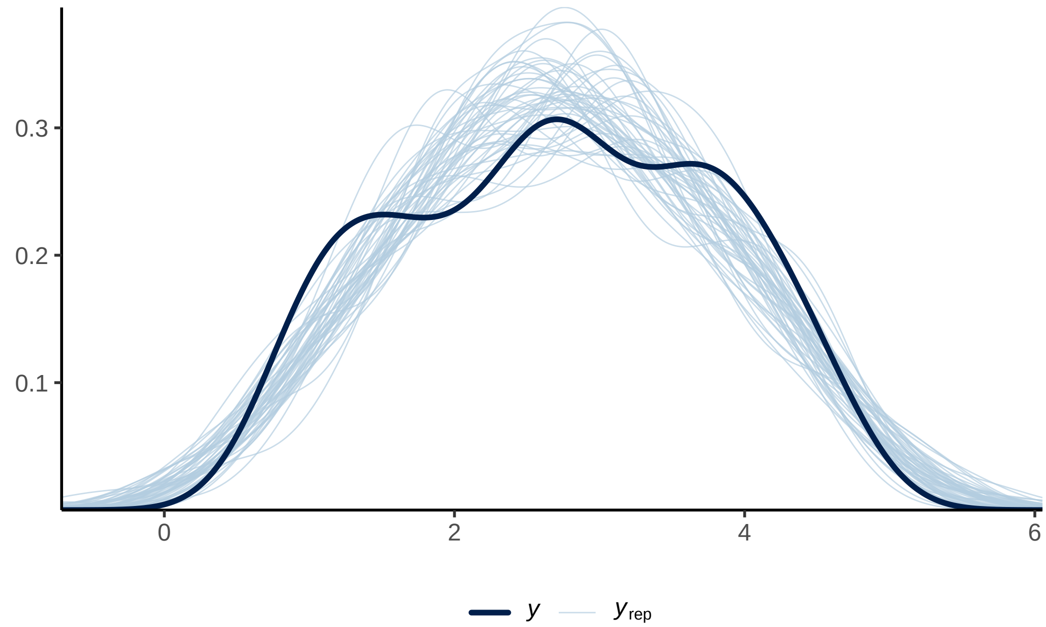
We conducted a posterior predictive check to evaluate how well the model predicts under-five mortality rates. Figure 5a illustrates the predictive distribution compared to the observed data. The close alignment between observed and predicted values indicates that the model captures the main trends in the data effectively.

In Figure 5b we compare the posterior with the prior. This shows that the data significantly updates the prior beliefs for all key parameters. The posterior distributions of predictors—vaccine coverage, health expenditure, and food production index—highlight the robustness of their effects in the model.

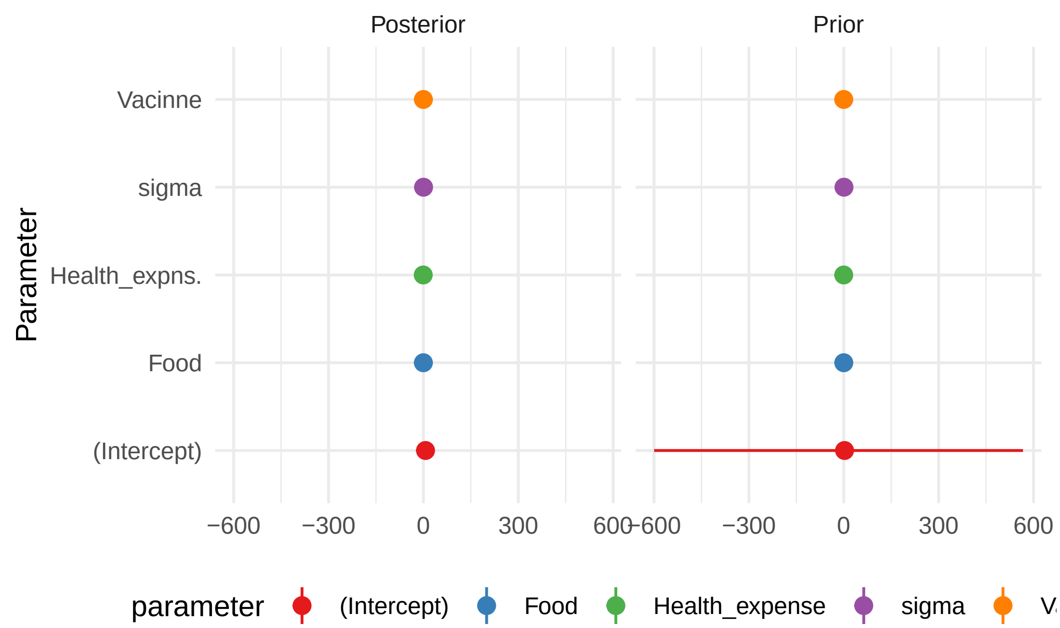
B.2 Diagnostics

Figure 6a is a trace plot. It shows adequate mixing of the Markov Chain Monte Carlo (MCMC) chains, indicating proper convergence. Additionally, the Rhat values for all parameters (Figure 6b) are below 1.05, further confirming convergence and the reliability of the parameter estimates.

Figure 6b is a Rhat plot. It shows no significant patterns, indicating that the model assumptions hold. Additionally, the Bayesian framework effectively quantifies uncertainty, with credible intervals for the predictors providing insight into their respective influences on mortality.

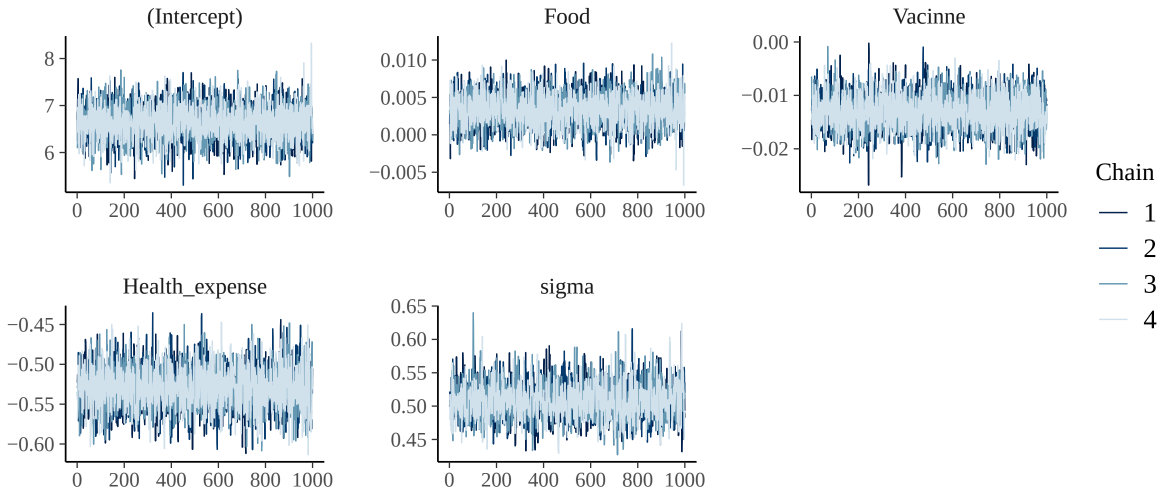


(a) Posterior prediction check

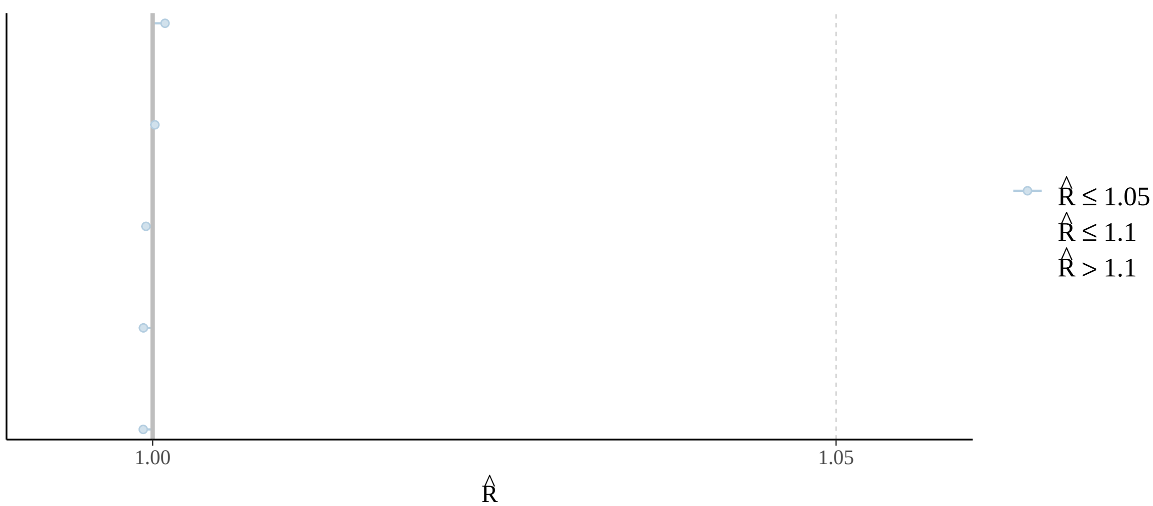


(b) Comparing the posterior with the prior

Figure 5: Examining how the model fits, and is affected by, the data



(a) Trace plot



(b) Rhat plot

Figure 6: Checking the convergence of the MCMC algorithm

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