Estimating levels and trends of early and late neonatal mortality in countries worldwide

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Introduction

Neonatal mortality rate (NMR), defined as the number of deaths in the first 28 days of life per 1000 live births, is an important component in the evaluation of countries' progress in reducing child mortality, and represents a significant portion of under-5 child mortality rate (U5MR). In particular, as U5MR has been decreasing, neonatal deaths have become an increasing fraction of under-5 mortality.

The increased focus on neonatal mortality in recent decades has largely been driven by the adoption of the Millennium Development Goals (MDG), and has continued as part the Sustainable Development Goals (SDG) agenda for international development, with specific goals calling for the end of preventable deaths of newborns and for all countries to reduce their neonatal mortality rate to at least as low as 12 deaths per 1000 live births by the year 2030 (United Nations 2025).

Globally, the number of neonatal deaths has declined, from 5.2 million in 1990 to 2.3 million in 2023 (UNICEF 2025), and while this is a significant progress, this decline has been markedly slower than the decline in post-neonatal under-5 mortality rates. Without significant action in preventing neonatal mortality, 65 countries are estimated to fall short of achieving the SDG target for NMR (Hug et al. 2019).

What is particularly noteworthy is that the wast majority of neonatal deaths tend to occur in the first week of life, and at least half of these are believed to occur within the first 24h since birth (Belizán et al. 2012; Lawn, Cousens, and Zupan 2005). Early neonatal deaths — defined as deaths of newborns in the first 0 to 7 days of life — therefore make up a large fraction of the under-5 child mortality rate. And although SDG targets have played an important role in the increased focus on neonatal deaths, considerably less attention has been paid to the timing of neonatal deaths. Understanding the timing of neonatal mortality, however, is critical in formulating specific, targeted interventions for the reduction of overall neonatal mortality. Therefore an important piece in the continued improvements of child survival is having reliable estimates of the timing of neonatal mortality.

Much like with the estimation of NMR, challenges in the estimation of the timing of NMR exist due to data availability and data quality. This is particularly true in low-income, low-resource countries and communities, where the burden of neonatal mortality is usually the largest and the information on these deaths is least likely to be available or of good quality.

In this work we aim to estimate the rate of early and late neonatal mortality from 1990 to 2022 for all countries in the world, with projected estimates through to the year 2030. Below we describe the data and the modeling framework we propose, along with some preliminary results.

Data and Methods

Data Sources

Data on early and late neonatal mortality — defined as deaths of newborns occurring in the 0-7 and 8-28 days of life respectively — come from three broadly defined sources: vital registration (VR) systems, sample vital registration (SVR) systems, and retrospective household-based surveys (such as Demographic and Health Surveys

(DHS), Multiple Indicators Cluster Surveys (MICS), World Fertility Surveys (WFS)). Data for each country can come from one or more of these sources, and sources can vary across countries, and within countries over time. Additionally, data sources vary substantially by quality. Usually, high-income, high-resource countries have higher quality VR data series with high coverage. On the other hand, low-income, low-resource places may have incomplete vital registration systems, and data, when and where available, usually come from household surveys, which can be of poorer quality, with larger sampling errors and often with reported values differing substantially across surveys for overlapping time periods.

In our analytic samples, there were a total of 3893 country-year observations and 178 countries had at least one available observation on early and late neonatal mortality. The vast majority of the country-year observations came from VR data (around 70%), and large differences exist in data sources between regions of the world. For instance, nearly all data for Europe and North America come from VR data series. In contrast, roughly 90% or available data for Sub-Saharan Africa come from retrospective surveys.

Modeling framework

Our aim in this work is to produce estimates of the early and late neonatal mortality rates for all countries in the world for the period 1990 to 2022. However, the varying quality and coverage of the available data along with considerable data missingness in certain contexts over the period of interest, pose challenges to our estimation process. Our modeling approach should be able to account and adjust for various data characteristics. It should also be able to produce estimates for setting in which we have no available data. Our modeling framework should be flexible enough to follow reliable, high quality data relatively closely, but our estimates should not be too unduly influenced by highly uncertain observations or erratic trajectories. To address some of these issues we propose a bivariate Bayesian hierarchical penalized splines model to estimates the levels of early and late NMR for all countries in the world over the period 1990-2022, with projections out to year 2030. As early and late neonatal mortality rates often co-vary, our proposed modeling framework assumes these outcomes (on the log scale) follow a bivariate normal distribution, allowing us to accounts for such correlation. The model also includes relevant covariates, in order to more reasonably estimate trends over time in context where there is insufficient data.

Below we describe an initial iteration of our model. We begin by setting some notation. Let $\boldsymbol{m_{c,t}} = (m^E_{c,t}, m^L_{c,t})$ denote the early (E) and late (L) neonatal mortality rate (NMR) for country c at time t. We model the rates jointly as follows

$$\begin{pmatrix} \log(m^E_{c,t}) \\ \log(m^L_{c,t}) \end{pmatrix} \sim \mathrm{N}\Big(\begin{pmatrix} \mu^E_{c,t} \\ \mu^L_{c,t} \end{pmatrix}, \; \boldsymbol{\Sigma} \Big) \tag{1}$$

where we assume that the log of early and late neonatal mortality rates follow a bivariate normal distribution centered around a mean $\boldsymbol{\mu_{c,t}} = (\mu^E_{c,t}, \mu^L_{c,t})$ and a shared covariance matrix, $\boldsymbol{\Sigma}$. We further decompose the covaraince matrix $\boldsymbol{\Sigma}$ using its correlation matrix $\boldsymbol{\Omega}$ and standard deviation terms $\boldsymbol{\sigma} = (\sigma^E, \sigma^L)$, such that $\boldsymbol{\Sigma} = \mathrm{diag}(\boldsymbol{\sigma})\boldsymbol{\Omega}\mathrm{diag}(\boldsymbol{\sigma})$. We assign an LKJ(1) prior to $\boldsymbol{\Omega}$, and Student's t with 3 degrees of freedom prior to the standard deviation terms. For each country-year level observation i, we define the mean for each neonatal mortality rates as

$$\mu^j_{c[i],t[i]} = \beta^j_{\mathrm{GLOBAL}} + \beta^j_{\mathrm{U5MR}}\mathrm{logU5MR}_{c[i],t[i]} + \beta^j_{r[i]} + \beta^j_{c[i]} + \nu^j_{c[i],t[i]} \;, \text{ for } j \in \{\mathrm{E}, \mathrm{L}\} \tag{2}$$

where logU5MR is a predictor in the model (based on UN IGME-produced point estimates of the under-5 mortality rate for country c at time t). β_{GLOBAL} refers to the global intercept for each rate, $\beta_{r[i]}$ are region effects for region r, where regions are based on UN Sustainable Development Goals (SDG) regional groupings, and $\beta_{c[i]}$ refer to country effects for country c. These are modeled as $\beta_{\mathrm{GLOBAL}} \sim N(0,1)$, $\beta_{r[i]} \sim N(0, \sigma_r)$, $\beta_{c[i]} \sim N(0, \sigma_c)$ for both early and late NMR. For each rate, $\nu_{c[i],t[i]}$ captures a data-driven trend, modeled using a first-order penalized splines setup, designed to capture deviations in the country-specific time trend away from what would be expected based on the time trend of the country's under-5 mortality rate.

Preliminary findings and future work

Below we illustrate some preliminary results from the initial version of the model. Figure 1 presents country-level estimates of early and late neonatal mortality rates in four distinct contexts, Afghanistan (AFG), Albania (ALB), Japan (JPN), and Pakistan (PAK). Afghanistan is an example of a country with high burden of neonatal mortality for which we have no available data in the period of interest. By contrast, Japan has very low neonatal mortality and high quality, high coverage vital registration system. Pakistan is an example of high NMR country, where we have ample survey data, however the data are of lower quality with erratic observed trajectories. Finally, Albania is a smaller country with reasonably low neonatal mortality rate and a somewhat lacking vital registration system, where we have both survey and VR data. The estimated early and late neonatal mortality trends in Afghanistan, where there is no data, are to a large degree driven by the changes in U5MR estimates over time, which have greater uncertainty associated with them. By contrast, in Japan the trend is determined by changes in U5MR and the spline component — informed by high quality data — and estimated trajectories have much smaller uncertainty. In Pakistan there is ample survey data — though less certain and with erratic trajectories — covering the bulk of the period of interest, which informs the spline component of the model producing relatively smooth but highly uncertain estimates. Finally, Albania is an interesting example where observed data come from surveys and VR, both of which have higher uncertainty associated with them, but notably, for portion of the period of interest there is also a significant discrepancy between observed values of different data sources for the same time point. The model components here are attempting to capture that highly nonlinear behavior, however the final estimates require further scrutiny.

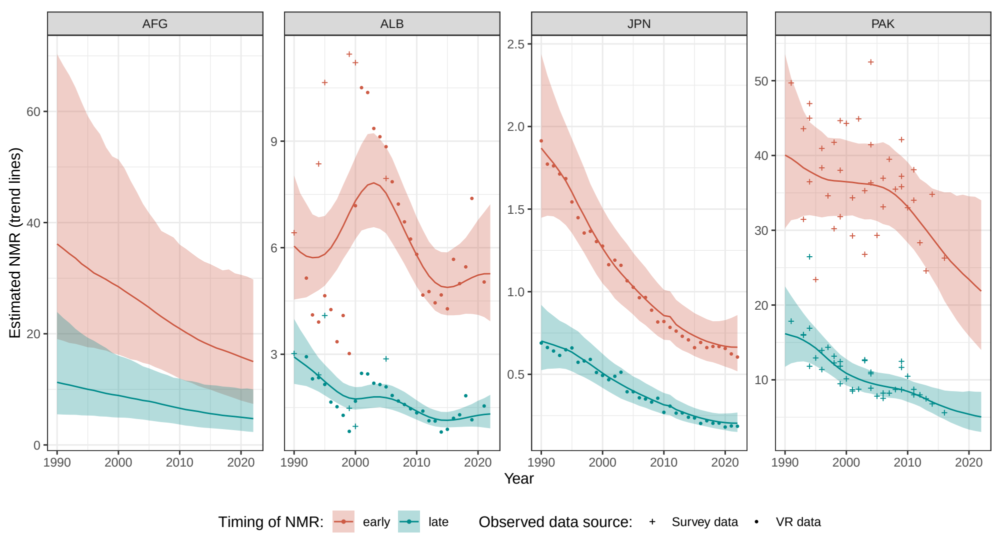

Figure 1: Estimated posterior medians for early and late NMR with 95% credible intervals for four different data and mortality burden contexts. Estimates are give for the period 1990-2022. Observed values are plotted along, with different shapes indicating different data sources. Note the difference in scale on the y-axis.

Moving forward, our work will focus on building on the initial model, by considering additional predictors, refining other components of the model, and carrying out validation exercises. We will also construct projections through to the year 2030. Additionally, we aim to examine and, where feasible, make adjustments for any non-sampling errors, potentially allowing such errors to vary by type and quality of data. In cases where vital registrations systems are incomplete or data come from retrospective household-based surveys, neonatal deaths are likely to be under-reported, and often misclassification of early neonatal deaths and stillbirths can occur. Future aspects of this work will additionally attempt to examine the degree of under-reporting and misclassification of neonatal deaths.

References

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