Racial disparities in premature births, fetal deaths and neonatal deaths: a multi-decrement lifetable approach

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Abstract

We propose a multiple-decrement life table approach to study fetal and neonatal outcomes across different population groups. This approach allows us to better understand and compare how risk evolves over the gestational period, providing evidence for how to best target health interventions. Using U.S. linked birth-infant death data, we encode the risk of all possible outcomes — fetal death, stillbirth, live birth by prematurity status, and neonatal death — throughout the fetal-neonatal period, from 20 weeks of gestation through 28 days of life. This enables us to compare both the age-specific risk and the cumulative risk for each outcome by racial and ethnic group. Initial work demonstrates that the non-Hispanic Black population has a heightened risk of all adverse outcomes, but the magnitude of the difference in risk depends on gestational age; in general, disparities are lowest in the mid-range of gestational ages.

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1 Introduction

There are large and persistent racial disparities in fetal and neonatal outcomes in the United States. Non-Hispanic black women are more likely to experience stillbirth, premature live birth, or the early death of their child during the neonatal period (MacDorman and Mathews 2011; Matoba, Mestan, and Collins 2021; Healy et al. 2006; Bryant et al. 2010). The neonatal mortality rate for the non-Hispanic black population was more than double that for the non-Hispanic white population in 2019 (6.85 deaths per 1000 live births versus 2.92 deaths per 1000 live births) (Ely and Driscoll 2021). Similarly, non-Hispanic black Americans suffer a fetal mortality rate of over twice that of the non-Hispanic population (11.2 versus 5.1 deaths per 1000 live births) (Shannon M. Pruitt 2020). Disparities are similar when considering rates of other adverse fetal and neonatal outcomes. While these disparities are addressed individually in large literatures in demography, public health, and medicine, there is little prior work that considers them in concert. But there is a need to consider the cumulative and compounding risk of multiple potential outcomes in one comprehensive framework, to better understand how risk evolves over the gestational period for different population groups, and how best to target health interventions.

In this paper we propose a multiple-decrement life table approach to study fetal and neonatal outcomes across different population groups. Multiple-decrement life tables are an extension of the classical single-decrement life table method, allowing exits from a population to be studied by the reason of exit. While multiple-decrement life tables are commonly used to study mortality across the life course by cause of deaths, they can be used to study other phenomena that have multiple exit paths, such as marriage or fertility outcomes (Preston, Heuveline, and Guillot 2000). Here, we extend the life table framework to tabulate outcomes by gestational age (rather than age after birth), and tabulate decrements based on gestational outcome (death or birth, by prematurity) and also eventual neonatal outcome (death or survival). This approach allows us to encode the risk of all possible outcomes throughout the fetal-neonatal period, from 20 weeks of gestation through 28 days of life, and thus to compare both the age-specific risk and the cumulative risk for each outcome by racial and ethnic group. While the analytical framework presented here is broadly applicable, we are uniquely placed to study the US context due to the availability of linked birth and infant death data (NBER 2020).

Fetal life tables have occasionally been used in the past. Early efforts were made to model spontaneous abortion early in pregnancy (French and Bierman 1962; Shapiro, Jones, and Densen 1962). Some studies have included later pregnancy, and a few have extended the life table approach to include neonatal mortality (Mellin 1962; Smith 2001). However, fetal life tables remain relatively uncommon, and we know of no previous work that has used life tables to study racial disparities in the full complement of fetal and neonatal outcomes.

The remainder of this abstract is structured as follows. We first define the full set of decrements considered over the course of gestation and the neonatal period. We discuss notation and methods for the multi-decrement life tables, and the data used to study the US context. We then present some preliminary results, both in terms of probabilities of events by gestational age, and eventual probabilities of events by gestational age. We then outline future directions for this work.

2 Framework and definitions of possible outcomes

Figure 1 gives an overview of all possible outcomes considered from 20 weeks gestation and how the definitions relate to gestational age. Following definitions from the WHO, we define a stillbirth as a death after 28 weeks of pregnancy, but before or during birth. Any death at or after 20 weeks gestation but before 28 weeks gestational age is referred to as a fetal death. A premature birth is defined as one that occurs before the start of the 37th week of pregnancy. We divide live births by gestational age into the following categories: extremely preterm births occur before 28 weeks; very preterm between 28 and 32 weeks; moderate to late preterm births between 32 and 37 weeks; and full-term births 37 weeks or later. A neonatal death is defined as a death in the first 28 days of life.

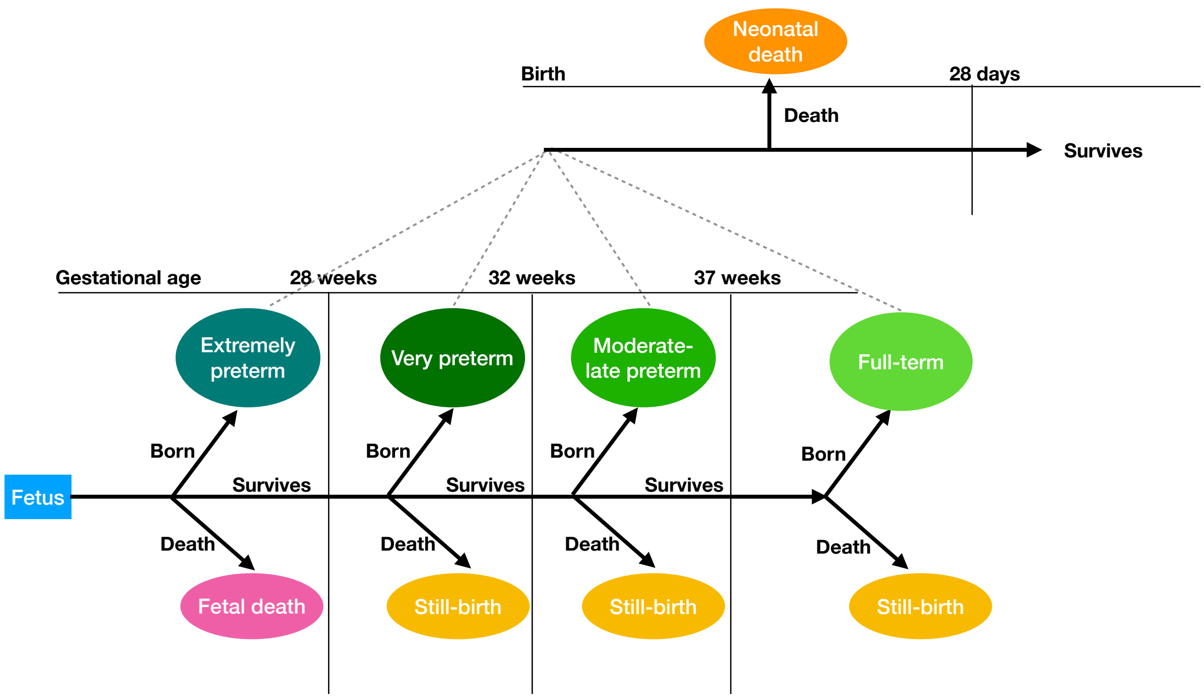

Figure 1: Outcomes considered from 20 weeks gestation to 28 days after birth.

3 Methods

The following section firstly defines notation used in life table calculations and then discusses a measure of lifetime risk, which is calculated to compare outcomes across population groups.

3.1 Core life table columns

Define x to be the gestational age in weeks. We consider increments in one week spanning the interval $x = 20$ to 42+. We consider exits from gestation due to different causes i. The complete set of causes i considered is:

- extremely premature live birth, survives to at least 28 days
- very premature live birth, survives to at least 28 days
- moderate-late premature live birth, survives to at least 28 days
- full-term live birth, survives to at least 28 days
- extremely premature live birth, neonatal death
- very premature live birth, neonatal death
- moderate-late premature live birth, neonatal death
- full-term live birth, neonatal death
- fetal death
- stillbirth

Following the usual life table notation, we define as follows:

- l_x to be the number of fetuses still in gestation at gestational age x. l_{20} is referred to as the radix (as we begin our life table at $x = 20$), which we set to be $100,000$.
- d_x is the number of fetuses that have exited gestation (i.e. either through a live birth or death) at gestational age x
- d_x^i refers to the number of fetus that have exited gestation due to cause i at gestational age x.
- q_x is the probability that a fetus of gestational age x will exit
- q_x^i is the cause-specific probability that a fetus of gestational age x will exit

3.2 'Lifetime' risk of outcomes about gestational age x

The columns defined above measure age-specific decrements and probabilities of exits. So for example, q_x is interpreted as, conditional on reaching gestational age x, the probability that a fetus will exit gestation before gestational age $x + 1$. These are equivalent to the usual age-specific death probabilities in a life table. However, an additional measure that is interesting in studying fetal outcomes is one of 'lifetime' risk, that is, the probability that a fetus will eventually exit through one of the causes i, conditional on reaching a certain gestational age x. These quantities are calculated as:

$$p_x^i = \frac{\sum_x^{\omega} d_x^i}{l_x}$$

where ω is the last gestational age group (in this case, 42+). This is the probability of experiencing outcome i at sometime in the future, conditional on having reached gestational age x: We can calculate these for each of the outcomes i listed above. These quantities are additive, and so can be combined in various ways. For example, we could sum the p_x^i over all causes i that involve premature births to get an estimate of the gestational lifetime risk of experiencing a premature birth. Additionally, one minus the sum across all causes i defined above, $1 - \sum_i p_x^i$, is equal to the probability of a full-term birth and survival through the neonatal period.

4 Data

Data on deaths in the first year of life come from the National Bureau of Economic Research collection of U.S. Birth Cohort Linked Birth and Infant Death Data of the National Center for Health Statistics' National Vital Statistics System (NVSS) (NBER 2020). We use the year 2013, as this is the most recent data available.

5 Preliminary results

In this section we describe some initial results and observations. To begin, for illustrative purposes, Table 1 shows a reduced multi-decrement life table calculated for non-Hispanic whites. Here we are only considering two possible outcomes: fetal death or live birth. The table shows the probability of exit due to live birth increases over gestational age, while the probability of fetal death decreases initially but then increases at late gestational ages.

Figure 2 illustrates the probability of fetal death by gestational age across different racial/ethnic groups. Probabilities of fetal death are initially high but decrease for all groups, and then increases toward the end of the gestational period (after around 35 weeks). In terms of racial differences, the probabilities of death are much higher for the Non-Hispanic Black population at the beginning of the period, while differences across racial/ethnic lines are less pronounced after around 30 weeks gestation.

Table 1: Fetal life table for non-Hispanic white population, with two possible outcomes: fetal death or live birth

x	lx	dx	dx_death	dx_livebirth	qx_death	qx_livebirth
20	100000.000	18.94715	16.552732	2.394420	0.0001655	0.0000239
21	99981.048	29.25357	24.829098	4.424472	0.0002483	0.0000443
22	99951.788	34.30267	26.130414	8.172261	0.0002614	0.0000818
23	99917.477	48.66920	23.788046	24.881151	0.0002381	0.0002490
24	99868.796	68.91766	14.210364	54.707300	0.0001423	0.0005478
25	99799.861	83.23213	11.972102	71.260032	0.0001200	0.0007140
26	99716.609	89.37434	6.454524	82.919819	0.0000647	0.0008316
27	99627.213	117.27455	6.194261	111.080284	0.0000622	0.0011150
28	99509.910	155.94964	3.799841	152.149799	0.0000382	0.0015290
29	99353.923	202.58878	4.268315	198.320470	0.0000430	0.0019961
30	99151.285	280.66771	5.881946	274.785764	0.0000593	0.0027714
31	98870.550	368.16816	5.361420	362.806740	0.0000542	0.0036695
32	98502.293	527.60532	5.205262	522.400063	0.0000528	0.0053034
33	97974.560	768.34868	5.569630	762.779048	0.0000568	0.0077855
34	97206.026	1328.95536	6.298367	1322.656995	0.0000648	0.0136067
35	95876.749	2105.42425	5.986051	2099.438196	0.0000624	0.0218973
36	93770.816	3825.86734	8.640734	3817.226605	0.0000921	0.0407080
37	89944.025	7959.73001	9.942050	7949.787964	0.0001105	0.0883859
38	81982.372	15189.16181	12.024154	15177.137658	0.0001467	0.1851268
39	66789.541	31003.05913	15.980153	30987.078979	0.0002393	0.4639511
40	35778.992	20649.01285	11.399523	20637.613325	0.0003186	0.5768081
41	15124.990	9336.78199	4.892946	9331.889047	0.0003235	0.6169848
42	5785.953	5784.55526	4.788841	5779.766419	0.0008277	0.9989308

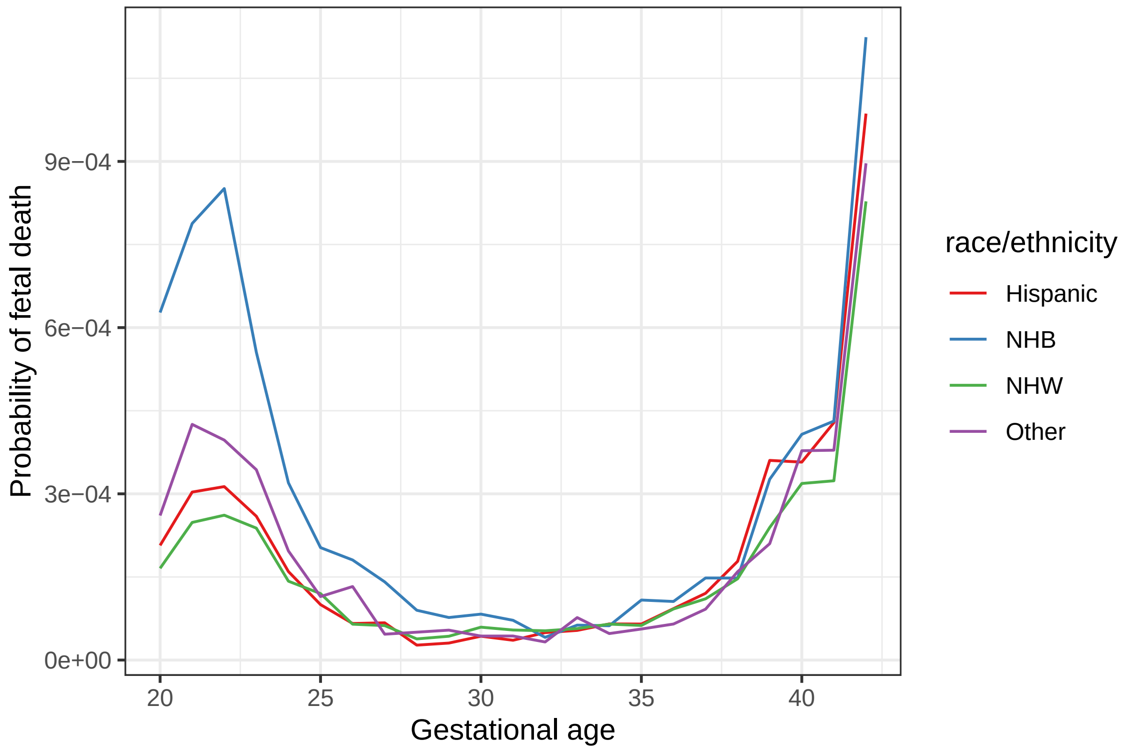

Figure 2: Conditional age-specific probability of fetal death by race/ethnicity

5.1 Lifetime risk of possible adverse outcomes

Turning now to the calculations of lifetime risk, Figure 3 shows the lifetime risk of neonatal death across gestational age for different racial/ethnic groups. These numbers are interpreted as the probability of experiencing a neonatal death sometime in the future, given the fetus has reached gestational age x. For example, at a gestational age of 20 weeks, fetuses of non-Hispanic black women have a 0.2% chance of eventually experiencing a neonatal death, more than double that of other racial/ethnic groups. The risk decreases with gestational age, as fetuses survive through the particularly risky earlier period, but racial disparities persist.

The previous graph considered risk of eventual neonatal death. Figure 4 considers lifetime risk of all possible outcomes together. These graphs suggest, for example, that Non-Hispanic black women have a ~0.75% chance of any adverse outcome at 20 weeks gestation. Racial differences appear particularly stark for early fetal deaths and extremely pre-term births.

In order to investigate disparities further, Figure 5 plots the ratio of Non-Hispanic white to other racial/ethnic groups of lifetime risk probabilities of fetal death, neonatal death, and both fetal and neonatal deaths across gestational age. Non-Hispanic blacks experience elevated risk of both outcomes across the full gestational period, with rates at least 1.2 times that of Non-Hispanic whites. For the Hispanic population, there are interesting patterns: while for fetal deaths, the risk is higher and increasing over the gestational period, births to Hispanic women have a lower risk of

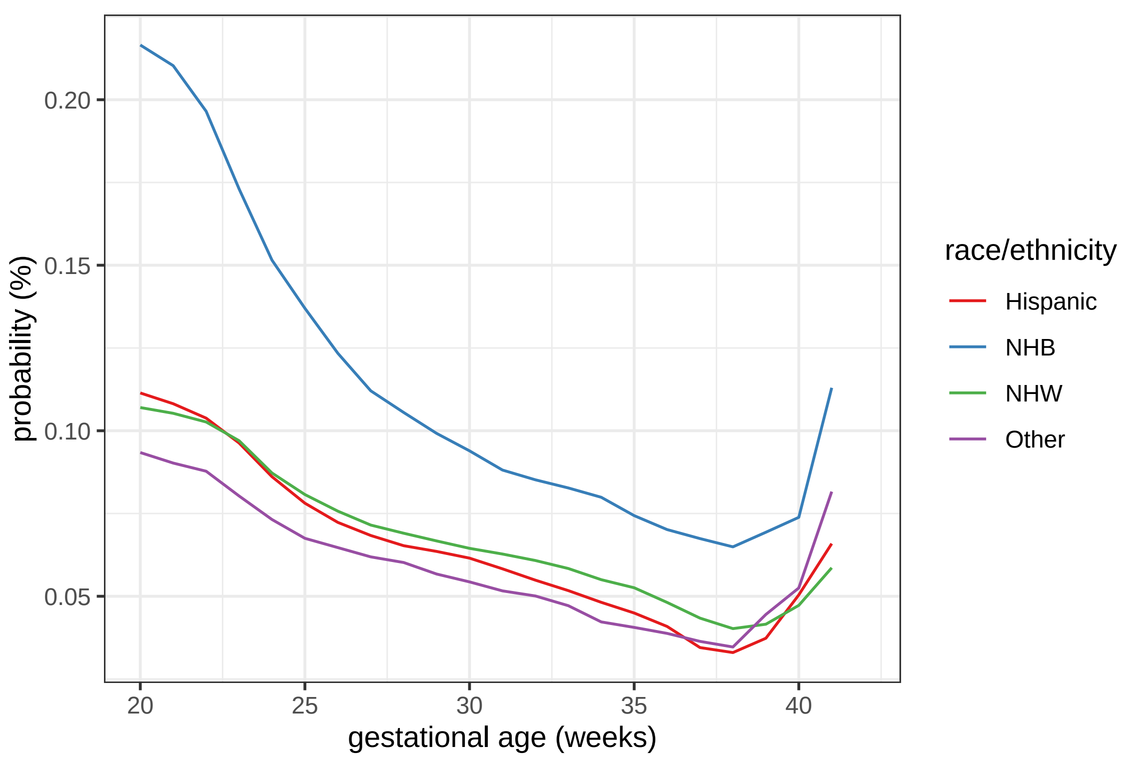

Figure 3: Probability of eventual neonatal death by race/ethnicity

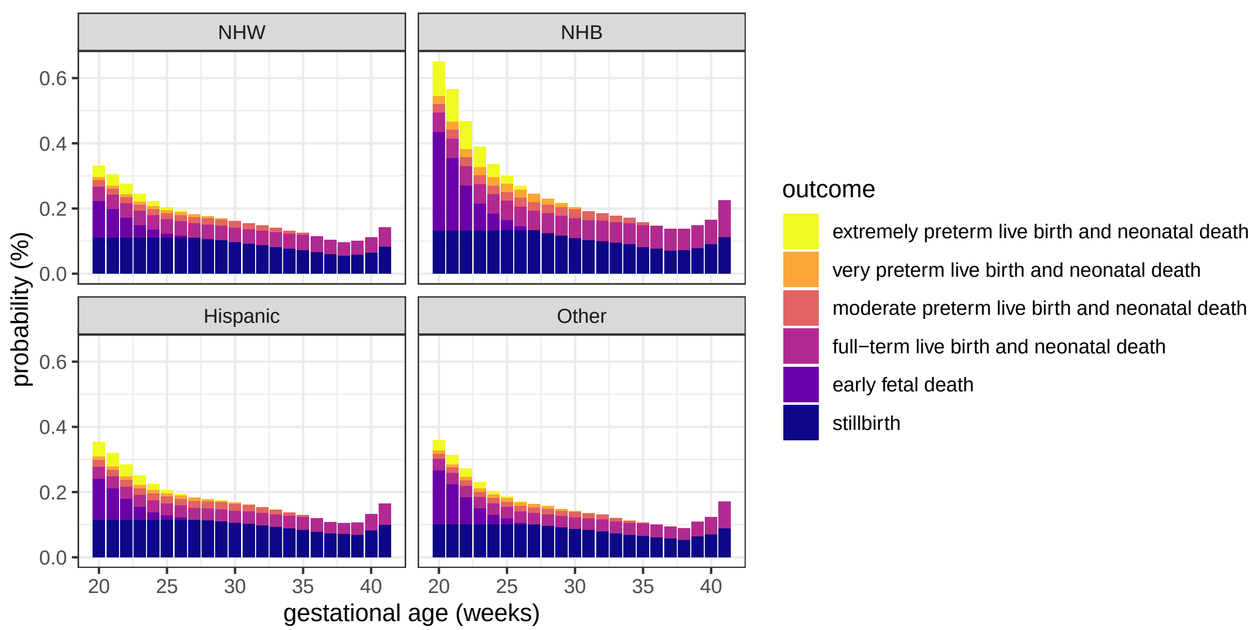

Figure 4: Probability of eventual outcomes by race/ethnicity

neonatal death at most gestational lengths, apart from very early and very late ages.

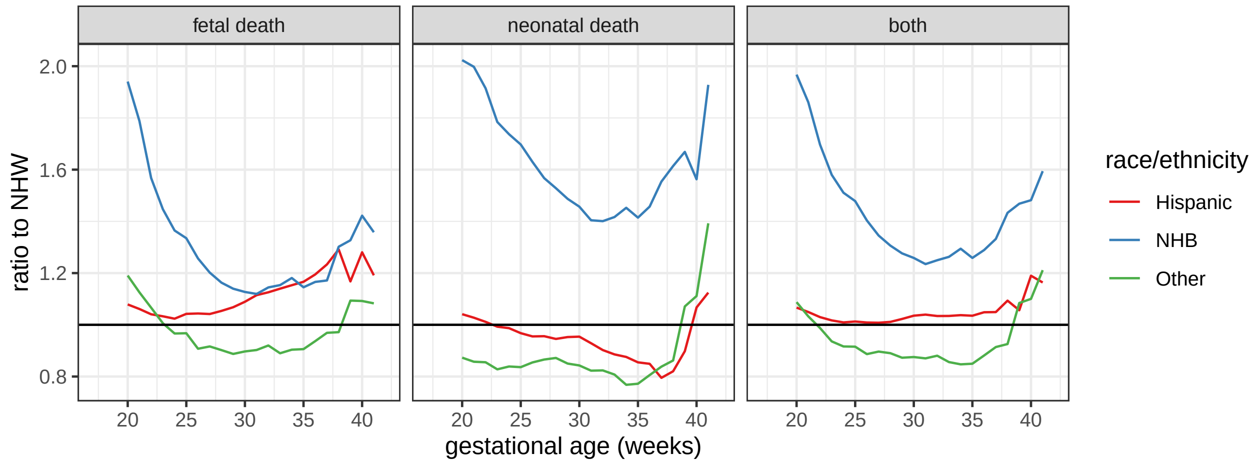

Figure 5: Ratio of probabilities of fetal and neonatal death to Non-Hispanic white probabilities

6 Summary and future work

In this abstract we presented a multi-decrement lifetable approach to studying racial differences in adverse outcomes across the gestational period. This framework, and in particular the calculation of 'lifetime risks' of different events, allows the full scope of potential outcomes to be assessed and the evolution over gestational age to be studied. Initial work demonstrates that the non-Hispanic black population has a heightened risk of all adverse outcomes, but the magnitude of the difference in risk depends on gestational age; in general, disparities are lowest in the mid-range of gestational ages. Future work will focus on more thoroughly understanding these disparities and their implications.

Another line of potential future work focuses on utilizing this multiple potential outcomes framework to assess and adjust for likely measurement error in fetal and neonatal outcomes. In many contexts, particularly in populations that have inadequate access to healthcare, it is sometimes difficult to distinguish between stillbirths and very early neonatal deaths. For example, it can be challenging to ascertain the presence of a heartbeat after the onset of labor, which means the classification of a death is unclear (Kc et al. 2020). In some populations, there may be different definitions of what constitutes a neonatal death, which means reported statistics are unreliably high or low. For example, countries such as Belarus, Russia, and Ukraine have historically had different definitions of 'live birth', which leads to an overcount of stillbirths and undercount of first-day neonatal mortality (Andreev 2020). Applying this multi-decrement approach to data from a number of different countries with good data in order to build up a picture of likely shares of different fetal and neonatal outcomes may help in adjusting data in less reliable contexts.

The current model includes only two types of decrement: unintended death and live birth. Induced abortion is also a possible outcome, and although it likely represents a tiny fraction of outcomes at all of the gestational ages studied — the average gestational age at abortion is 8 weeks, and in 2016, 95% of abortions occurred before 16 weeks (Guttmacher Institute 2019) — recent changes to abortion availability in the U.S. in the aftermath of the Dobbs v. Jackson Women's Health decision have made it likely that more abortion care will be delayed and will occur at later gestational ages (Kimport 2022). Estimating the distribution of these abortions is difficult, as abortion surveillance data does not include fine-grained information on gestational age, but new data availability may make it possible to include in the future.

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