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Projecting excess infant mortality in low- and middle-income countries during the COVID-19 pandemic based on forecasted declines in economic growth

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Abstract

Objectives: While COVID-19 has a relatively small direct impact on infant mortality, the pandemic is expected to indirectly increase mortality of this vulnerable group, particularly in low- and middle-income countries, through its effects on the economy and health system performance. Previous studies projected indirect mortality by modelling how hypothesized disruptions in health services will affect health outcomes. We provide alternative projections, relying on modelling of the relationship between aggregate income shocks and mortality.

Design: We construct a sample of 5.2 million births by pooling retrospective birth histories reported by women in Demographic and Health Surveys conducted in 83 low- and middle-income countries between 1985 and 2018. We employ regression models with country-specific fixed-effects and flexible time trends to estimate the impact of GDP per capita on infant mortality rate. We then use growth projections by the International Monetary Fund to predict the effect of the economic downturn in 2020 on infant mortality.

Results: We estimate 267,208 (137,341-397,075) excess infant deaths in 128 countries, corresponding to a 6.8% increase in the total number of infant deaths expected in 2020.

Conclusions: The findings underscore the vulnerability of infants to the negative income shocks such as those imposed by the COVID-19 pandemic. While efforts towards prevention and treatment of COVID-19 remain paramount, the global community should also strengthen social safety nets and assure continuity of essential health services.

Strengths and limitations of this study

- Our study highlights the impact of the decline in economic growth induced by the COVID-19 pandemic on all-cause infant mortality, an overlooked consequence of the crisis, and adopts rigorous methods to provide mortality projections.
- In comparison to previous projections of mortality during the pandemic that are based on assumptions regarding magnitudes of health service disruptions, our estimates account for additional mechanisms, mainly increased household poverty.
- Our estimates may represent a lower bound of the actual excess mortality if the current economic downturn is accompanied by larger disruptions to provision of essential health services relative to previous downturns.
- We estimate the short-term impact of GDP fluctuations on mortality while longer-term implications for mortality and other adverse outcomes might also exist.

- The analysis ascribes the difference between October 2019 and October 2020 economic growth projections for 2020 solely to the pandemic, even though some countries have also experienced other shocks, such as natural disasters or political crises.

Introduction

Reducing morality risk in the wake of the COVID-19 pandemic is a paramount public concern. While direct mortality risk as a result of COVID-19 infection has garnered the majority of attention in global media and policy discussions, indirect mortality may be substantial. Health and social policies should not lose sight of excess indirect mortality caused by such factors as the interruption of essential health services and the general economic downturn brought on by the pandemic. This study attempts to quantify the expected indirect mortality over the pandemic period for one especially vulnerable sub-population – infants – by modeling the impact of projected economic decline on the likelihood of infant survival.

Studies from diverse settings find negligible direct mortality rates for children and infants due to COVID-19 (1). However, stringent containment measures and the ensuing economic downturn, as well as the need to reallocate health system resources towards pandemic response, have shifted many social determinants of mortality such as the ability to afford nutritious foods and to access essential health care. Unlike economic crises in high income countries, which appear to lower mortality (2), economic crises in low-income countries generally increase mortality among vulnerable groups, namely young children and the elderly. Earlier studies have documented a robust relationship between short-term fluctuation in aggregate income and all-cause infant mortality in low- and middle-income countries (3) (4) (5) (6) (7) (8).

At the very start of the COVID-19 pandemic, modelling exercises predicted that the interruption of essential health services will be severe (9) (10) (11) (12) (13) and perhaps the world will experience 250,000 to 1.15 million young child deaths (14) in the first six months of the pandemic. Recent studies indicate that barriers to access essential health care in low- and middle-income are not just a theoretical concern documenting, for example, disruptions in immunization services in Pakistan and Sierra Leone (15) (16), and access to primary care in rural South Africa (17). At the same time, the global economy is expected to contract 4.9% in the first year of the pandemic (18) and the global poverty count is projected to increase by 120 million people (19). This economic decline creates food insecurity (20) and lowers the affordability among vulnerable households of key goods and services necessary for child survival.

In this study, we estimate the impact of the economic downturn on infant mortality by modelling the relationship between GDP fluctuations and infant mortality, following the approach of Baird et al (2011) (5). We link GDP per capita data to 5.2 million retrospective birth histories reported in 83 Demographic and Health Surveys (DHS) conducted in low- and middle-income countries between 1985 and 2017. Then, we use growth projections by International Monetary Fund (IMF) World Economic Outlook (WEO) to predict the effect of the economic downturn in 2020 on infant mortality.

Data and Methods

To estimate the impact of GDP per capita on infant mortality rate, we rely on two sources of data. Data on GDP per capita is taken from the World Development Indicators. We use values adjusted for purchasing power parity, corresponding to 2011 US dollars. Data on infant mortality are constructed from retrospective birth histories reports in all Demographic and Health Surveys conducted in 83 low- and middle-income countries between 1985 and 2018. The surveys used in the analysis are listed in Table A1 in the appendix. The combined sample totals 5.2 million births, of which 27 and 55 percent are from low- and lower-middle income countries. The sample's infant mortality rate per 1000 births is 85, 61 and 37 for low-, lower-middle and upper-middle income countries respectively.

We estimate the relation between aggregate income change and infant mortality with the following framework:

$$D_{ict} = \alpha_c + \beta logGDP_{ct} + \gamma_1 t_{ct} + \gamma_2 t_{ct}^2 + \gamma_3 t_{ct}^3 + \varepsilon_{ict}$$

D_{ict} is a binary indicator taking the value 1 if child i in country c died in the first 12 months of life during year t. $logGDP$ is the natural logarithm of per capita GDP, and $\varepsilon_{iact}$is the error term. The α and γ coefficients identify country-specific fixed effects and a cubic time trend, respectively. Standard errors are clustered at the country level. We estimate the semi-elasticity of infant mortality to aggregate income decline separately by country income level, as classified by the World Bank 2020 income groups. To explore the robustness of the findings, both we and Baird et al. (2011) find appreciably similar results with linear or quadratic time trends, as well as alternative recall periods for births (5 or 15 years as opposed to the default 10 years).

As a projection of the aggregate income shock in each country, we compare growth predictions for the same calendar period made before and then during the pandemic. Specifically, we use the IMF WEO 2020 growth rates projected in October 2019 and in October 2020. We define the difference between the two projections as the growth shortfall that is likely attributed to the pandemic and the ensuing economic crisis. Between October 2019 and October 2020, the IMF revised downwards growth projections for all countries. The average shortfall for lower- and middle-income countries is 9.3 percent. The average projected shortfall in low-income countries, 5.9 percent, is less than half of the projected average shortfall in upper-middle income countries, 12.5 percent.

To calculate the number of excess infant deaths that were likely caused by the pandemic in each country, we multiply the projected growth shortfalls with the β coefficient from the regression specification above. We then multiply by the projected number of births in each country, taken from the United Nation's World Population Prospects 2019. The total number of births are projected for the five-year period 2015-2020 and we assume equal amount of births in each year. (The projections are available at population.un.org/wpp.)

Patient and Public Involvement

The study presents analysis of secondary data. There was no patient and public involvement.

Results

Estimation of the GDP-Mortality relationship

The regression coefficient estimates are presented in Table 1. A 1% decrease in GDP per capita is associated with 0.23 increase in infant mortality per 1,000 children born in low- and middle-income countries. These estimates vary substantially by income group. A 1% decrease in per capita GDP is associated with increases of 0.48, 0.24 and 0.16 in infant mortality per 1,000 children born in low- lower-middle- and upper-middle-income countries, respectively.

Our estimate for the relationship between GDP and infant mortality is significantly lower than the estimate presented in Baird, Friedman and Schady (2011), using the same specification (5). This previous analysis estimated that a 1% decrease in GDP per capita is associated with a 0.40 increase in infant mortality per 1000 children born in low- and middle-income countries. Two things might drive this difference. First, we have a different composition of countries given that more DHS datasets are available. Our analysis includes 83 countries relative to 59 in the earlier paper. Second, resiliency to income shocks may have improved over time through higher average household incomes and more developed health systems.

Projection of excess infant mortality in 2020

In Table 2, we report the estimated excess infant mortality in 128 low- and middle-income countries, along with 95% confidence interval around the estimate. In total, we estimate 267,208 (137,341-397,075) excess infant deaths in lower- and middle-income countries due to the growth shortfall in 2020. Most of the excess mortality is estimated to occur in the 46 lower-middle income countries, even though the income-mortality semi-elasticity in low-income countries (LIC) is almost twice the size of that in lower-middle income countries (LMIC). This is explained both by the fact that there are more countries and more populous countries in the LMIC group and because the IMF projects larger growth shortfalls in that group. It is worth noting than more than a third of the excess infant mortality is projected to be in India (99,642). India has the highest number of annual births (24,238,000) as well as a particularly large projected shortfall of -17.3%. Because of this, South Asia is the region with the highest expected excess infant mortality although there are only 8 countries included in the analysis. Nigeria and China are distant second and third with projected excess infant deaths of 11,904 and 10,835.

To benchmark our projections, we calculate the expected infant mortality in the absence of the pandemic for the 128 countries. According to the World Bank's World Development Indicators, estimated infant mortality rates in low-, lower-middle, and upper-middle countries were 48, 37 and 11 deaths per 1000 live births in 2019. We multiply these rates by the annual number of births in each country to forecast a total of 3,953,466 deaths. The excess deaths we project correspond to an increase of 6.8 percent in the total number of expected infant deaths.

Discussion

In this study, we have assessed the potential impact of the 2020 economic downturn caused by the COVID-19 pandemic on infant mortality – we estimate almost 270,000 excess infant deaths in the 12 months following the pandemic start. A useful comparison point to this estimate is the 28,000 to 50,000 excess infant deaths estimated for Africa after the financial crisis in 2009 (7). Our Africa estimate in 2020 is 82,239 (37,858-126,620) infant deaths. This higher projection reflects the larger estimated GDP shortfalls. Several mechanisms are likely driving this increase in mortality among children aged 0-1: impoverishment at the household level will lead to worse nutrition and care practices for infants and reduced ability to access health services, while the economic crisis might also affect the supply and quality of services offered by the health systems. It is difficult to compare our estimates with other projections focusing on health system disruption as the main driver because the methodology, the age range and the time period are different. The most comparable study in its focus on child mortality which predicts 253,500 to 1,157,000 additional under-5 child deaths over the first six months of the pandemic, depending on the scenario severity (14).

Our estimates of excess infant mortality are not additional to previous projections but an alternative. Our reduced form approach yields estimates that already incorporate at least some consequences of reduced utilization of health services, i.e those reductions that have historically arose during severe economic downturns. Our estimates also directly account for other mechanisms, mainly increased poverty. As past economic crises were not driven by a pandemic, it is possible that the world will experience a higher mortality shock than implied by the historic income-mortality semi-elasticity. The current economic downturn is accompanied by more severe disruptions to the supply of effective health services. Therefore, our projections are likely to provide a lower bound of the actual excess mortality. However, the projections reported in this paper ascribe the difference between the WEO October 2019 and October 2020 economic growth projections for 2020 solely to the pandemic, even though some countries have also experienced other shocks, such as natural disasters or political crises.

One limitation of our analysis is that it relies on retrospective birth histories in Demographic and Health Surveys. In the absence of comprehensive and robust vital registration statistics in most of the countries included in this analysis, this is probably the best possible data source, but such household survey data might be affected by recall bias, especially for birth and deaths occurring long before the survey date. For this reason, we have explored the stability of estimates to alternative birth recall periods and find appreciably similar results. Another limitation is that we only consider the short-term impact of GDP fluctuations on mortality while longer-term implications might also exist. Lastly, the projections reported in this paper ascribe the difference between the WEO October 2019 and October 2020 economic growth projections for 2020 solely to the pandemic, even though some countries have also experienced other shocks, such as natural disasters or political crises.

The large number of excess infant deaths estimated in our analysis underscores the vulnerability of this age group to negative aggregate income shocks such as those induced by the COVID-19 pandemic. While we focused on the 0-1 age group, our estimates are suggestive of other vulnerabilities not directly attributable to COVID-19 among other segments of the population such as children aged 1-5, pregnant women, and the elderly. As countries, health systems, as well as the global community, continue efforts to prevent and treat COVID-19, we may also consider resources to stabilize health systems and strengthen social safety nets to mitigate the human, social and economic consequences of the pandemic and related lockdown policies.

Declaration of interests

We declare no competing interests.

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Contributor Statement

All authors contributed to the conceptualization, design of the methodology and the writing. GS conducted the formal analysis and JF and GS validated the results.

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References

1. *Assessing the age specificity of infection fatality rates for COVID-19: systematic review, meta-analysis, and public policy implications.* **Levin, Andrew T., William P. Hanage, Nana Owusu-Boaitey, Kensington B. Cochran, Seamus P. Walsh, and Gideon Meyerowitz-Katz.** 2020, European journal of epidemiology, pp. 1-16.

2. *Health effects of economic crises.* **Ruhm, Christopher J.** 2016, Health Economics, pp. 6-24.

3. *Wealthier is Healthier.* **Pritchett, Lant, and Lawrence H. Summers.** 1996, Journal of Human Resources, pp. 841-868.

4. *Fatal fluctuations? Cyclicality in infant mortality in India.* **Bhalotra, Sonia.** 2010, Journal of Development Economics, pp. 7-19.

5. *Aggregate income shocks and infant mortality in the developing world.* **Baird, Sarah, Jed Friedman, and Norbert Schady.** 2011, Review of Economics and statistics, pp. 847-856.

6. *Economic crises, maternal and infant mortality, low birth weight and enrollment rates: evidence from Argentina's downturns.* **Cruces, Guillermo, Pablo Glüzmann, and Luis Felipe López Calva.** 2012, World Development, pp. 303-314.

7. *How many infants likely died in Africa as a result of the 2008–2009 global financial crisis?* **Friedman, Jed, and Norbert Schady.** 2013, Health Economics , pp. 611-622.

8. *Effects of economic downturns on child mortality: a global economic analysis, 1981–2010.* **Maruthappu, Mahiben, Robert A. Watson, Johnathan Watkins, Thomas Zeltner, Rosalind Raine, and Rifat Atun.** 2017, BMJ global health.

9. *Routine childhood immunisation during the COVID-19 pandemic in Africa: a benefit–risk analysis of health benefits versus excess risk of SARS-CoV-2 infection.* **Abbas, Kaja, Simon R. Procter, Kevin van Zandvoort, Andrew Clark, Sebastian Funk, Tewodaj Mengistu, Dan Hogan et al.** 10, 2020, The Lancet Global Health, Vol. 8, pp. e1264-e1272.

10. *Potential impact of the COVID-19 pandemic on HIV, tuberculosis, and malaria in low-income and middle-income countries: a modelling study.* **Hogan, Alexandra B., Britta L. Jewell, Ellie Sherrard-Smith, Juan F. Vesga, Oliver J. Watson, Charles Whittaker, Arran Hamlet et al.** 10, 2020, The Lancet Global Health, Vol. 8, pp. e1132-e1141.

11. *Potential effects of disruption to HIV programmes in sub-Saharan Africa caused by COVID-19: results from multiple mathematical models.* **Jewell, Britta L., Edinah Mudimu, John Stover, Debra Ten Brink, Andrew N. Phillips, Jennifer A. Smith, Rowan Martin-Hughes et al.** 9, 2020, The Lancet HIV, Vol. 7, pp. e629-e640.

12. *The potential public health consequences of COVID-19 on malaria in Africa.* **Sherrard-Smith, Ellie, Alexandra B. Hogan, Arran Hamlet, Oliver J. Watson, Charlie Whittaker, Peter Winskill, Fatima Ali et al.** 1, 2020, Nature medicine, Vol. 26, pp. 1411-1416.

13. **Organization, World Health.** *Pulse survey on continuity of essential health services during the COVID-19 pandemic.* 2020.

14. *Early estimates of the indirect effects of the COVID-19 pandemic on maternal and child mortality in low-income and middle-income countries: a modelling study.* **Roberton, Timothy, Emily D. Carter, Victoria B. Chou, Angela R. Stegmuller, Bianca D. Jackson, Yvonne Tam, Talata Sawadogo-Lewis, and Neff Walker.** 7, 2020, The Lancet Global Health, Vol. 8, pp. e901-e908.

15. *Impact of COVID-19 pandemic response on uptake of routine immunizations in Sindh, Pakistan: an analysis of provincial electronic immunization registry data.* **Chandir, Subhash, Danya Arif Siddiqi, Mariam Mehmood, Hamidreza Setayesh, Muhammad Siddique, Amna Mirza, Riswana Soundardjee et al.** 45, 2020, Vaccine , Vol. 38, pp. 7146-7155.

16. *Child healthcare and immunizations in sub-Saharan Africa during the COVID-19 pandemic.* **Buonsenso, Danilo, Bianca Cinicola, Memenatu Ngaima Kallon, and Francesco Iodice.** Frontiers in pediatrics, p. 517.

17. *Access to primary healthcare during lockdown measures for COVID-19 in rural South Africa: an interrupted time series analysis.* **Siedner, Mark J., John D. Kraemer, Mark J. Meyer, Guy Harling, Thobeka Mngomezulu, Patrick Gabela, Siphephelo Dlamini et al.** 2020, BMJ open.

18. **Fund, International Monetary.** *World Economic Outlook, October 2020: A Long and Difficult Ascent.* . 2020.

19. **CHRISTOPH LAKNER, NISHANT YONZANDANIEL GERSZON MAHLERR. ANDRES CASTANEDA AND AGUILARHAOYU WU.** Updated estimates of the impact of COVID-19 on global poverty: Looking back at 2020 and the outlook for 2021.

20. *Falling living standards during the COVID-19 crisis: Quantitative evidence from nine developing countries.* **DENNIS EGGER, EDWARD MIGUEL, SHANA S. WARREN, ASHISH SHENOY, ELLIOTT COLLINS, DEAN KARLAN, DOUG PARKERSON, A. MUSHFIQ MOBARAK, GÜNTHER FINK, CHRISTOPHER UDRY, MICHAEL WALKER, JOHANNES HAUSHOFER, MAGDALENA LARREBOURE, SUSAN ATHEY, PAULA LOPEZ-PENA, SALIM B.** 2021, Science Advances.

22. *The impact of the COVID-19 epidemic on tuberculosis control in China.* **Fei, Huang, Xia Yinyin, Chen Hui, Wang Ni, Du Xin, Chen Wei, Li Tao et al.** 2020, The Lancet Regional Health-Western Pacific.

23. *Effect of the COVID-19 pandemic on viral hepatitis services in sub-Saharan Africa.* **Lemoine, Maud, Jin Un Kim, Gibril Ndow, Sulayman Bah, Karen Forrest, John Rwegasha, Marielle Bouyou et al.** 2020, The Lancet Gastroenterology & Hepatology, pp. 966-967.

Tables

Table 1: Relationship between aggregate income shocks and infant mortality rate per 1,000 children, by World Bank country income groups

Low-income countries	Lower-middle-income countries	Upper-middle-income countries	Low- and middle-income countries
-46.85***	-23.73***	-16.08***	-23.12***
(17.71)	(5.50)	(6.80)	(9.38)

Notes: Overall number of observed births is 5,273,350. The table presents coefficient estimates from regressions of infant mortality log per capita GDP with time trends and country fixed effects. There are four income groupings for countries; the country income groups follow the World Bank classification for fiscal year 2021.
* p<0.10, ** p<0.05, *** p<0.01.

Table 2: Projection of excess infant deaths with 95% confidence intervals, by World Bank country income groups and regions

	Estimate	95% CI	Countries
Total	267,318	137,341 – 397,075	128
By income group:			
Low-income economies	65,628	25,787-105,468	29
Lower-middle income economies	158,638	98,400-218,875	46
Upper-middle income economies	42,942	13,153-72,732	53
By region:			
Sub-Saharan Africa	82,239	37,858-126,620	48
East Asia and Pacific	32,537	16,106-48,968	19
Europe and Central Asia	7,962	3,284-12,640	20
Latin America and the Caribbean	17,202	5,844-28,559	23
Middle East and North Africa	14,127	5,710-22,544	10
South Asia	113,141	68,539-157,743	8

Notes: The definitions of income groups and regions are based on the World Bank country group categorization for the 2021 fiscal year.

Appendix Table A1: Demographic and Health Surveys datasets used in the analysis

Low-income	Lower-middle income	Upper-middle income
Afghanistan 2015 Benin 1996, 2001, 2006, 2012, 2018 Burkina Faso 1993, 1999, 2003, 2010 Burundi 1987, 2011, 2017 Central African Republic 1995 DRC 2007, 2014 Ethiopia 2000, 2005, 2011, 2016 Gambia 2013 Guinea 1999, 2005, 2012, 2018 Haiti 1995, 2000, 2006, 2012, 2017 Liberia 2007, 2013 Madagascar 1992, 1997, 2004, 2009 Malawi 1992, 2000, 2005, 2010, 2016 Mali 1987, 1996, 2001, 2006, 2013, 2018 Mozambique 1997, 2004, 2011, 2015 Nepal 1997, 2001, 2006, 2011, 2017 Niger 1992, 1998, 2006, 2012 Rwanda 1992, 2000, 2008, 2011, 2015 Sierra Leone 2008, 2013 Tajikistan 2012, 2017 Tanzania 1999, 2005, 2012, 2016 Togo 1988, 1998, 2014 Uganda 1989, 1995, 2001, 2006 Yemen 1992, 2013	Angola 2016 Bangladesh 1994, 1997, 2000, 2004, 2007, 2011, 2014 Bolivia 1989, 1994, 1998, 2004, 2008 Cambodia 2000, 2006, 2011, 2014 Cameroon 1991, 1998, 2004, 2011, 2018 Comoros 1996, 2012 Republic of Congo 2005, 2012 Cote d'Ivoire 1994, 1999, 2012 Egypt 1989, 1993, 1996, 2003, 2005, 2008, 2014 El Salvador 1985 Eswatini 2007 Ghana 1988, 1994, 2003, 2008, 2014 Honduras 2006, 2012 India 1993, 1999, 2006, 2016 Indonesia 1987, 1991, 1994, 1997, 2003, 2007, 2012, 2017 Kenya 1989, 1993, 1998, 2003, 2009, 2014 Kyrgyz Republic 1997, 2012 Lesotho 2005, 2010, 2014 Moldova 2005 Morocco1987, 1992, 2004 Myanmar 2016 Nicaragua 1998, 2001 Nigeria 1990, 2003, 2008, 2013, 2018 Pakistan 1991, 2007, 2013, 2018 Papua New Guinea 2018 Philippines 1993, 1998, 2003, 2008, 2013, 2017 Sao Tome and Principe 2009 Senegal 1986, 1993, 1997, 2011, 2012-2018* Sudan 1990 Timor Leste 2010, 2016 Tunisia 1988 Ukraine 2007 Uzbekistan 1996 Vietnam 1997, 2002 Zambia 1992, 1997, 2002, 2007, 2014, 2018 Zimbabwe 1989, 1994, 1999, 2006, 2011, 2015	Albania 2009, 2018 Armenia 2000, 2005, 2010, 2016 Azerbaijan 2006 Brazil 1986, 1992, 1996 Colombia 1986, 1990, 1995, 2000, 2005, 2010, 2016 Dominican Republic 1986, 1991, 1996, 1999, 2002, 2007, 2013 Ecuador 1987 Gabon 2001, 2012 Guatemala 1987, 1995, 1999, 2015 Guyana 2009 Jordan 1990, 1997, 2002, 2007, 2012, 2018 Kazakhstan 1995, 1999 Maldives 2009, 2017 Mexico 1987 Namibia 1992, 2000, 2007, 2013 Paraguay 1990 Peru 1986, 1992, 1996, 2000, 2004-2012*

Notes: some surveyed spanned over more than one calendar year. In these cases, the last year of the survey is indicated.
* Senegal and Peru had special continuous survey. Peru had annual survey between 2004 and 2012 and Senegal completed annual surveys between 2012 to 2018.

Appendix Table A2: Projections of growth shortfall and excess infant mortality in lower- and middle-income countries

Country	Region [a]	Number of annual birth 2015-2020 (in thousands) [b]	WEO projections of 2020 growth [c]			Excess mortality projection		
			October 2019 projection	October 2020 projection	Growth Shortfall	estimate	95% lower bound	95% higher bound
Panel A: Lower Income Economies [a]								
Afghanistan	SAR	1205	3.5	-5.0	-8.5	4888	1921	7855
Benin	AFR	413	6.7	2.0	-4.7	930	365	1494
Burkina Faso	AFR	745	6.0	-2.0	-8.0	2852	1120	4583
Burundi	AFR	433	0.5	-3.2	-3.7	775	305	1246
Central African Republic	AFR	165	5.0	-1.0	-5.9	468	184	752
Chad	AFR	648	5.4	-0.7	-6.1	1894	744	3043
Congo, Dem. Rep.	AFR	3434	3.9	-2.2	-6.0	9925	3900	15951
Eritrea	AFR	106	3.9	-0.6	-4.5	226	89	364
Ethiopia	AFR	3514	7.2	1.9	-5.3	8832	3470	14193
Gambia, The	AFR	87	6.4	-1.8	-8.2	343	135	550
Guinea	AFR	449	6.0	1.4	-4.5	970	381	1559
Guinea-Bissau	AFR	66	4.9	-2.9	-7.8	245	96	393
Haiti	LAC	271	1.2	-4.0	-5.2	674	265	1084
Liberia	AFR	158	1.6	-3.0	-4.6	345	136	555
Madagascar	AFR	852	5.3	-3.2	-8.5	3454	1357	5551
Malawi	AFR	614	5.1	0.6	-4.5	1323	520	2126
Mali	AFR	787	5.0	-2.0	-7.0	2631	1034	4229
Mozambique	AFR	1099	6.0	-0.5	-6.5	3441	1352	5530
Nepal	SAR	562	6.3	0.0	-6.3	1681	660	2701
Niger	AFR	1023	6.1	0.5	-5.6	2717	1067	4366
Rwanda	AFR	390	8.1	2.0	-6.1	1142	449	1835
Sierra Leone	AFR	255	4.7	-3.1	-7.7	945	371	1519
Somalia	AFR	622	3.2	-1.5	-4.7	1398	549	2246
South Sudan	AFR	386	8.2	4.1	-4.1	757	297	1216
Tajikistan	ECA	281	4.5	1.0	-3.5	470	185	756
Tanzania	AFR	2052	5.7	1.9	-3.8	3732	1466	5998
Togo	AFR	260	5.3	0.0	-5.3	659	259	1059
Uganda	AFR	1614	6.2	-0.3	-6.5	5022	1973	8071
Yemen, Rep.	MNA	865	2.0	-5.0	-7.0	2890	1136	4644

Panel B: Lower-Middle Income Economies [a]								
Angola	AFR	1243	1.2	-4.0	-5.2	1523	945	2102
Bangladesh	SAR	2946	7.4	3.8	-3.6	2550	1581	3518
Bhutan	SAR	13	7.2	0.6	-6.6	21	13	29
Bolivia	LAC	247	3.8	-7.9	-11.7	685	425	945
Cabo Verde	AFR	11	5.0	-6.8	-11.7	30	18	41
Cambodia	EAP	366	6.8	-2.8	-9.5	828	514	1143
Cameroon	AFR	887	4.2	-2.8	-6.9	1461	906	2016
Comoros	AFR	26	4.2	-1.8	-6.1	38	24	52
Congo, Rep.	AFR	171	2.8	-7.0	-9.8	398	247	549
Côte d'Ivoire	AFR	890	7.3	1.8	-5.5	1161	720	1602
Djibouti	AFR	21	6.0	-1.0	-7.0	34	21	47
Egypt	MNA	2584	5.9	3.5	-2.3	1424	883	1964
El Salvador	LAC	118	2.3	-9.0	-11.3	315	196	435
Eswatini	AFR	30	0.5	-3.5	-4.0	29	18	39
Ghana	AFR	871	5.6	0.9	-4.7	968	600	1335
Honduras	LAC	207	3.5	-6.6	-10.1	496	308	684
India	SAR	24238	7.0	-10.3	-17.3	99642	61806	137478
Indonesia	EAP	4842	5.1	-1.5	-6.6	7549	4683	10416
Kenya	AFR	1469	6.0	1.0	-5.0	1743	1081	2404
Kiribati	EAP	3	2.3	-1.1	-3.4	3	2	4
Kyrgyz Republic	ECA	155	3.4	-12.0	-15.4	566	351	782
Lao PDR	EAP	167	6.5	0.2	-6.3	250	155	345
Lesotho	AFR	57	-0.2	-4.8	-4.6	62	39	86
Mauritania	AFR	147	5.9	-3.2	-9.1	318	197	439
Micronesia, Fed. Sts.	EAP	3	0.8	-3.8	-4.6	3	2	4
Moldova	ECA	41	3.8	-4.5	-8.3	81	50	112
Mongolia	EAP	77	5.4	-2.0	-7.4	134	83	185
Morocco	MNA	682	3.7	-7.0	-10.7	1725	1070	2380
Myanmar	EAP	948	6.3	2.0	-4.3	959	595	1323
Nicaragua	LAC	134	-0.8	-5.5	-4.7	151	94	208
Nigeria	AFR	7377	2.5	-4.3	-6.8	11904	7384	16424
Pakistan	SAR	5994	2.4	-0.4	-2.7	3891	2413	5368
Papua New Guinea	EAP	232	2.6	-3.3	-5.8	322	200	444
Philippines	EAP	2178	6.2	-8.3	-14.4	7466	4631	10301

Senegal	AFR	544	6.8	-0.7	-7.4	961	596	1325
Solomon Islands	EAP	21	2.9	-5.0	-7.9	39	24	54
Sudan	AFR	1339	-1.5	-8.4	-6.9	2182	1353	3010
São Tomé and Príncipe	AFR	7	3.5	-6.5	-10.0	16	10	22
Timor-Leste	EAP	37	5.0	-6.8	-11.8	105	65	144
Tunisia	MNA	204	2.4	-7.0	-9.5	458	284	632
Ukraine	ECA	426	3.0	-7.2	-10.2	1032	640	1424
Uzbekistan	ECA	703	6.0	0.7	-5.3	884	548	1219
Vanuatu	EAP	9	3.1	-8.3	-11.4	23	14	32
Vietnam	EAP	1610	6.5	1.6	-4.9	1872	1161	2583
Zambia	AFR	622	1.7	-4.8	-6.5	963	597	1328
Zimbabwe	AFR	442	2.7	-10.4	-13.1	1375	853	1897
Nigeria	AFR	7377	2.5	-4.3	-6.8	11904	7384	16424
Pakistan	SAR	5994	2.4	-0.4	-2.7	3891	2413	5368
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Zambia	AFR	622	1.7	-4.8	-6.5	963	597	1328
Zimbabwe	AFR	442	2.7	-10.4	-13.1	1375	853	1897
Panel C: Upper-Middle Income Economies [a]								
Albania	ECA	34	4.0	-7.5	-11.6	63	19	107
Algeria	MNA	1032	2.4	-5.5	-7.9	1305	400	2211
Argentina	LAC	755	-1.3	-11.8	-10.5	1276	391	2161
Armenia	ECA	42	4.8	-4.5	-9.3	62	19	105
Azerbaijan	ECA	169	2.1	-4.0	-6.1	167	51	282
Belarus	ECA	112	0.3	-3.0	-3.3	59	18	100

Belize	LAC	8	2.1	-16.0	-18.1	23	7	39
Bosnia and Herzegovina	ECA	27	2.6	-6.5	-9.1	40	12	68
Botswana	AFR	56	4.3	-9.6	-14.0	126	39	214
Brazil	LAC	2934	2.0	-5.8	-7.8	3700	1133	6267
Bulgaria	ECA	63	3.2	-4.0	-7.2	73	22	124
China	EAP	16978	5.8	1.9	-4.0	10835	3319	18351
Colombia	LAC	739	3.6	-8.2	-11.8	1407	431	2383
Costa Rica	LAC	70	2.5	-5.5	-8.0	91	28	153
Dominican Republic	LAC	208	5.2	-6.0	-11.2	375	115	636
Ecuador	LAC	336	0.5	-11.0	-11.5	621	190	1051
Equatorial Guinea	AFR	43	-5.0	-6.0	-1.0	7	2	12
Fiji	EAP	19	3.0	-21.0	-24.0	73	22	124
Gabon	AFR	67	3.4	-2.7	-6.1	65	20	111
Georgia	ECA	54	4.8	-5.0	-9.8	86	26	145
Grenada	LAC	2	2.7	-11.8	-14.5	4	1	7
Guatemala	LAC	423	3.5	-2.0	-5.5	377	115	639
Guyana	LAC	16	85.6	26.2	-59.4	149	46	252
Iran	MNA	1552	0.0	-5.0	-5.0	1257	385	2128
Iraq	MNA	1104	4.7	-12.1	-16.7	2972	910	5034
Jamaica	LAC	47	1.0	-8.6	-9.6	73	22	124
Jordan	MNA	215	2.4	-5.0	-7.4	255	78	433
Kazakhstan	ECA	389	3.9	-2.7	-6.6	413	127	700
Lebanon	MNA	117	0.9	-25.0	-25.9	488	149	827
Libya	MNA	126	0.0	-66.7	-66.6	1353	414	2292
Malaysia	EAP	527	4.4	-6.0	-10.4	882	270	1494
Maldives	SAR	7	6.0	-18.6	-24.6	28	9	48
Mauritius	AFR	13	3.8	-14.2	-18.0	38	12	64
Mexico	LAC	2224	1.3	-9.0	-10.3	3670	1124	6216
Montenegro	ECA	7	2.5	-12.0	-14.5	17	5	29
Namibia	AFR	70	1.6	-5.9	-7.4	83	26	141
North Macedonia	ECA	23	3.4	-5.4	-8.8	32	10	54
Paraguay	LAC	143	4.0	-4.0	-8.0	185	57	313
Peru	LAC	574	3.6	-13.9	-17.6	1621	497	2746
Romania	ECA	192	3.5	-4.8	-8.3	256	78	433
Russia	ECA	1858	1.9	-4.1	-6.0	1788	548	3029

Samoa	EAP	5	4.4	-5.0	-9.4	7	2	12
Serbia	ECA	84	4.0	-2.5	-6.5	87	27	148
South Africa	AFR	1185	1.1	-8.0	-9.1	1730	530	2931
Sri Lanka	SAR	339	3.5	-4.6	-8.1	441	135	747
St. Lucia	LAC	2	3.2	-16.9	-20.1	7	2	12
St. Vincent and the Grenadines	LAC	2	2.3	-7.0	-9.3	2	1	4
Suriname	LAC	11	2.5	-13.1	-15.6	27	8	45
Thailand	EAP	725	3.0	-7.1	-10.2	1183	362	2004
Tonga	EAP	3	3.7	-2.5	-6.2	3	1	4
Turkey	ECA	1318	3.0	-5.0	-8.0	1689	517	2861
Turkmenistan	ECA	139	6.0	1.8	-4.3	95	29	161
Venezuela, RB	LAC	528	-10.0	-25.0	-15.0	1273	390	2155

[a] The country classification into income and region groups follows the World Bank classification for fiscal year 2021. AFR = sub-Saharan Africa; EAP = East Asia and Pacific; ECA = European and Central Asia; LAC = Latin America and Caribbean; MNA = Middle East and North Africa SAR = South Asia;
[b] Number of births projected by the United Nations World Population Prospects 2019.
[c] Projections by the IMF World Economic Outlook for 2020.

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How many infants may have died in low- and middle-income countries in 2020 due to the economic contraction accompanying the COVID-19 pandemic? Mortality projections based on forecasted declines in economic growth

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How many infants may have died in low- and middle-income countries in 2020 due to the economic contraction accompanying the COVID-19 pandemic? Mortality projections based on forecasted declines in economic growth

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Abstract

Objectives: While COVID-19 has a relatively small direct impact on infant mortality, the pandemic is expected to indirectly increase mortality of this vulnerable group in low- and middle-income countries through its effects on the economy and health system performance. Previous studies projected indirect mortality by modelling how hypothesized disruptions in health services will affect health outcomes. We provide alternative projections, relying on modelling the relationship between aggregate income shocks and mortality.

Design: We construct a sample of 5.2 million births by pooling retrospective birth histories reported by women in Demographic and Health Surveys conducted in 83 low- and middle-income countries between 1985 and 2018. We employ regression models with country-specific fixed-effects and flexible time trends to estimate the impact of GDP per capita on infant mortality rate. We then use growth projections by the International Monetary Fund to predict the effect of the economic downturn in 2020 on infant mortality.

Results: We estimate 267,208 (112,000-422,415) excess infant deaths in 128 countries, corresponding to a 6.8% (2.8%-10.7%) increase in the total number of infant deaths expected in 2020.

Conclusions: The findings underscore the vulnerability of infants to the negative income shocks such as those imposed by the COVID-19 pandemic. While efforts towards prevention and treatment of COVID-19 remain paramount, the global community should also strengthen social safety nets and assure continuity of essential health services.

Strengths and limitations of this study

- To project the impact of the economic downturn associated with the COVID-19 pandemic on infant mortality, our study links GDP per capita data to 5.2 million retrospective birth histories reported in 83 Demographic and Health Surveys (DHS) conducted in low- and middle-income countries between 1985 and 2017.
- While previous projections of indirect mortality, not due to COVID-19 infections but nevertheless caused by the pandemic, have been based on assumptions regarding magnitudes of health service disruptions, our estimates account for additional mechanisms, mainly increased household poverty.
- Our estimates may represent a lower bound of the actual excess mortality if the current economic downturn is accompanied by larger disruptions to provision of essential health services relative to previous downturns.

- We estimate the short-term impact of GDP fluctuations on mortality while longer-term implications for mortality and other adverse outcomes may also arise.
- The analysis ascribes the difference between October 2019 and October 2020 economic growth projections for 2020 solely to the pandemic, even though some countries have also experienced other shocks, such as natural disasters or political crises.

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Introduction

Reducing morality risk in the wake of the COVID-19 pandemic is a paramount public concern. While direct mortality risk as a result of COVID-19 infection has garnered the majority of attention in global media and policy discussions, indirect mortality may be substantial. Health and social policies should not lose sight of excess indirect mortality caused by such factors as the interruption of essential health services and the general economic downturn brought on by the pandemic. This study attempts to quantify the expected indirect mortality over the pandemic period for one especially vulnerable sub-population – infants – by modeling the impact of projected economic decline on the likelihood of infant survival.

Studies from diverse settings find negligible direct mortality rates for children and infants due to COVID-19 (1). However, stringent containment measures and the ensuing economic downturn, as well as the need to reallocate health system resources towards pandemic response, have influenced many social determinants of mortality such as the ability to afford nutritious foods and to access essential health care. Unlike economic crises in high income countries, which appear to lower mortality (2), economic crises in low-income countries generally increase mortality among vulnerable groups, namely young children and the elderly. Earlier studies have documented a robust relationship between short-term fluctuation in aggregate income and all-cause infant mortality in low- and middle-income countries (3) (4) (5) (6) (7) (8).

At the very start of the COVID-19 pandemic, modelling exercises predicted that the interruption of essential health services will be severe (9) (10) (11) (12) (13) (14) and perhaps the world will experience 250,000 to 1.15 million young child deaths (15) in the first six months of the pandemic. Recent studies indicate that barriers to access essential health care in low- and middle-income are not just a theoretical concern documenting, for example, disruptions in immunization services in Pakistan and Sierra Leone (16) (17), and access to primary care in sub-Saharan Africa (18) (19). At the same time, the global economy is expected to contract 4.9% in the first year of the pandemic (20) and the global poverty count is projected to increase by 120 million people (21). Based on historical data, this economic decline is likely to be associated with higher mortality in excess of COVID-19 fatalities (22), especially in developing economies and will create food insecurity (23) and lower the affordability among vulnerable households of key goods and services necessary for child survival.

In this study, we estimate the impact of the economic downturn on infant mortality by modelling the relationship between GDP fluctuations and infant mortality, following the approach of Baird et al (2011) (5). We link GDP per capita data to 5.2 million retrospective birth histories reported in 83 Demographic and Health Surveys (DHS) conducted in low- and middle-income countries between 1985 and 2017. Then, we use growth projections by International Monetary Fund (IMF) World Economic Outlook (WEO) to predict the effect of the economic downturn in 2020 on infant mortality.

Data and Methods

To estimate the impact of changes in aggregate income on infant mortality, we rely on two sources of data. Data on GDP per capita is taken from the World Development Indicators. We use values adjusted for purchasing power parity, corresponding to 2011 US dollars. Data on infant mortality are constructed from retrospective birth history reports in all Demographic and Health Surveys conducted in 83 low- and middle-income countries between 1985 and 2018. The surveys used in the analysis are listed in Table A1 in the appendix. The combined sample totals 5.2 million births, of which 27 and 55 percent are from low- and lower-middle income countries. The sample's infant mortality rate per 1000 births is 85, 61 and 37 for low-, lower-middle and upper-middle income countries respectively.

We estimate the relation between aggregate income change and infant mortality with the following framework:

$$D_{ict} = \alpha_c + \beta logGDP_{ct} + \gamma_{1c}t_{ct} + \gamma_{2c}t_{ct}^2 + \gamma_{3c}t_{ct}^3 + \varepsilon_{ict}$$

$\boldsymbol{D_{ict}}$ is a binary indicator taking the value 1 if child i in country c died in the first 12 months of life during year t. $logGDP$ is the natural logarithm of per capita GDP, and $\varepsilon_{iact}$is the error term. The α and γ coefficients identify country-specific fixed effects and a country-specific cubic time trend, respectively. Standard errors are clustered at the country level. We estimate the semi-elasticity of infant mortality to aggregate income decline separately by country income level, as classified by the World Bank 2020 income groups, as well as overall. Low-income economies are defined by a gross national income (GNI) per capita of less than 1,035 USD in 2019. Lower middle-income economies are defined by a GNI between 1,036 and 4,045 USD and the range for upper middle-income economies is between 4,046 and 12,535 USD. To explore the robustness of the findings, both we and Baird et al. (2011) (5) find appreciably similar results with linear or quadratic time trends, as well as alternative recall periods for births (5 or 15 years as opposed to the default 10 years).

As a projection of the aggregate income shock in each country, we compare growth predictions for the same calendar period made before and then during the pandemic. Specifically, we use the IMF WEO 2020 growth rates projected in October 2019 and in October 2020. We define the difference between the two projections as the growth shortfall that is likely attributed to the pandemic and the ensuing economic crisis. Between October 2019 and October 2020, the IMF revised downwards the growth projections for all countries. The average shortfall for lower- and middle-income countries is 9.3 percent. The average projected shortfall in low-income countries, 5.9 percent, is less than half of the projected average shortfall in upper-middle income countries, 12.5 percent.

To calculate the number of excess infant deaths that were likely caused by the pandemic in each country, we multiply the projected growth shortfalls with the β coefficient from the regression specification above. We then multiply by the projected number of births in each country, taken from the United Nation's World Population Prospects 2019. The total number of births are projected for the five-year period 2015-2020 and we assume equal proportion of births for each year. (The projections are available at population.un.org/wpp.)

Patient and Public Involvement

The study presents analysis of secondary data. There was no patient and public involvement.

Results

Estimation of the GDP-Mortality relationship

The regression coefficient estimates are presented in Table 1. A 1% decrease in GDP per capita is associated with a 0.23 increase in infant mortality per 1,000 children born in low- and middle-income countries. These estimates vary substantially by income group. A 1% decrease in per capita GDP is associated with increases of 0.48, 0.24 and 0.16 in infant mortality per 1,000 children born in low- lower-middle- and upper-middle-income countries, respectively.

Our estimate for the relationship between GDP and infant mortality is significantly lower than the estimate presented in Baird, Friedman and Schady (2011), using the same specification (5). This previous analysis estimated that a 1% decrease in GDP per capita is associated with a 0.40 increase in infant mortality per 1000 children born in low- and middle-income countries. Two things might drive this difference. First, we have a different composition of countries given that more DHS datasets are available. Our analysis includes 83 countries relative to 59 in the earlier paper. Second, resiliency to income shocks may have improved over time through higher average household incomes and more developed health systems.

Projection of excess infant mortality in 2020

In Table 2, we report the estimated excess infant mortality in 128 low- and middle-income countries, along with 95% confidence interval around the estimate. The results by income group and region presented in Table 2 are aggregations of the country level projections presented in Appendix Table A2. In total, we estimate 267,208 (112,000-422,415) excess infant deaths in lower- and middle-income countries due to the growth shortfall in 2020. Most of the excess mortality is estimated to occur in the 46 lower-middle income countries, even though the income-mortality semi-elasticity in low-income countries (LIC) is almost twice the size of that in lower-middle income countries (LMIC). This is explained both by the fact that there are more countries and more populous countries in the LMIC group and because the IMF projects larger growth shortfalls in that group. It is worth noting than more than a third of the excess infant mortality is projected to be in India (99,642). India has the highest number of annual births (24,238,000) as well as a particularly large projected shortfall of -17.3%. Because of this, South Asia is the region with the highest expected excess infant mortality although there are only 8 countries included in the analysis. Nigeria and China are a distant second and third with projected excess infant deaths of 11,904 and 10,835.

To benchmark our projections of excess infant deaths, we assess the percentage increase in infant mortality these additional deaths represent. To that end, we calculate the expected infant mortality in the absence of the pandemic for the 128 countries. According to the World Bank's World Development Indicators, estimated infant mortality rates in low-, lower-middle, and upper-middle countries were 48, 37 and 11 deaths per 1000 live births in 2019. We multiply these rates by the annual number of births in each country to forecast a total of 3,953,466 deaths. Assuming that infant mortality rate in 2020 would have been similar to that in 2019 if the COVID-19 outbreak hasn't occurred, the excess deaths we project correspond to an increase of 6.8 (2.8-10.7) percent in the total number of expected infant deaths.

Discussion

In this study, we have assessed the potential impact of the 2020 economic downturn caused by the COVID-19 pandemic on infant mortality – we estimate almost 270,000 excess infant deaths in the 12 months following the pandemic start. A useful comparison point to this estimate is the 28,000 to 50,000 excess infant deaths estimated for Africa after the financial crisis in 2009 (7). Our Africa estimate in 2020 is 82,239 (37,858-126,620) infant deaths. This higher projection reflects the larger estimated GDP shortfalls. Several mechanisms are likely driving this increase in mortality among children aged 0-1: impoverishment at the household level will lead to worse nutrition and care practices for infants and reduced ability to access health services, while the economic crisis might also affect the supply and quality of services offered by the health systems (19). It is difficult to compare our estimates with other projections focusing on health system disruption as the main driver as the methodology, the age ranges, and the time period are different. The most comparable study, with a focus on child mortality, predicts 253,500 to 1,157,000 additional under-5 child deaths over the first six months of the pandemic, depending on the scenario severity (15).

Our estimates of excess infant mortality are not additional to previous projections but serve as an alternative. Our reduced form approach yields estimates that already incorporate at least some consequences of reduced utilization of health services, i.e those reductions that have historically arose during severe economic downturns. Our estimates also directly account for other mechanisms, mainly increased poverty. As past economic crises were not driven by a pandemic, it is possible that the world will experience a higher indirect mortality shock than implied by the historic income-mortality semi-elasticity if the current economic downturn is accompanied by more severe disruptions to the supply of effective health services. Therefore, our projections may provide a lower bound of actual indirect mortality. On the other hand, the projections reported in this paper ascribe the difference between the WEO October 2019 and October 2020 economic growth projections for 2020 solely to the pandemic, even though some countries have also experienced other shocks, such as natural disasters or political crises.

One limitation of our analysis is that it relies on retrospective birth histories in Demographic and Health Surveys. In the absence of comprehensive and robust vital registration statistics in most of the countries included in this analysis, this is likely the most comprehensive data source available. However, such household survey data can be affected by recall bias, especially for birth and deaths occurring long before the survey date. For this reason, we have explored the stability of estimates to alternative birth recall periods and find appreciably similar results. Another limitation is that we only consider the short-term impact of GDP fluctuations on mortality while longer-term consequences might also exist. Longer-term impacts on the number of infant deaths could also occur through changes in fertility behavior but should not affect our projections for 2020. Although COVID-19 was first detected in the end of 2019, the outbreak was declared as pandemic only in March 2020. If there were impacts on fertility, they would impact births and infant mortality in 2021.

Regarding the reported confidence intervals for projected excess infant deaths in Table 2, note that these bounds may be regarded as conservative. This is because we first apply the 5th percentile lower bound and then the 95th percentile upper bound estimate of the mortality semi-elasticity to the projected growth contractions for all countries in order to estimate the bounds, thus imposing a perfect correlation of semi-elasticities across countries. If instead, each country receives its own independent draw from the distribution of semi-elasticities then there will be significantly tighter confidence bounds in expectation.

On the other hand, there may also be forecast error in either the country-level economic growth projections or in the projections of number of births, which is not directly modeled. Previous literature suggests these forecast errors have an expected mean of zero, with most deviations from forecast on the order of plus/minus one percentage point of economic growth or plus/minus three percent of total births (24) (25). To explore further the role of uncertainty in economic and demographic projections, we consider Monte Carlo simulations that model country-specific growth and birth projections with a slightly larger anticipated degree of error. Specifically, we simulate a draw for each country from growth projections that are uniformly distributed around the projection at +- 1.5 percentage points, and draws for the birth projection that are uniformly distributed around the projection at +- 4 percent. After 10,000 simulations we obtain a 95% CI of total excess deaths to be (251588, 283106). substantially narrower than the reported CI of (112000, 422415). This suggests that uncertainty in the true value of the growth-IMR semi-elasticity is the most influential parameter driving uncertainty in the projected total number of indirect infant deaths.

Regardless of the exact number of projected deaths, the large number of excess infant deaths estimated in our analysis underscores the vulnerability of this age group to negative aggregate income shocks such as those induced by the COVID-19 pandemic. While we focused on the 0-1 age group, our estimates are suggestive of other vulnerabilities not directly attributable to COVID-19 among other segments of the population such as children aged 1-5, pregnant women, and the elderly. As countries, health systems, and the wider global community continue efforts to prevent and treat COVID-19, we should also consider resources to stabilize health systems and strengthen social safety nets in order to mitigate the human, social and economic consequences of the pandemic and related lockdown policies.

Declaration of interests

We declare no competing interests.

Funding

This study did not require funding.

Data availability

Requests to access the data can be submitted on the Demographic and Health Surveys Program at dhsprogram.com.

Ethics Statement

Ethics approval was not sought as the study presents results of an analysis of secondary data and does not involve human participants.

Contributor Statement

All authors contributed to the conceptualization, design of the methodology and the writing. GS conducted the formal analysis and JF and GS validated the results.

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References

1. *Assessing the age specificity of infection fatality rates for COVID-19: systematic review, meta-analysis, and public policy implications.* **Levin, Andrew T., William P. Hanage, Nana Owusu-Boaitey, Kensington B. Cochran, Seamus P. Walsh, and Gideon Meyerowitz-Katz.** 2020, European journal of epidemiology, pp. 1-16.

2. *Health effects of economic crises.* **Ruhm, Christopher J.** 2016, Health Economics, pp. 6-24.

3. *Wealthier is Healthier.* **Pritchett, Lant, and Lawrence H. Summers.** 1996, Journal of Human Resources, pp. 841-868.

4. *Fatal fluctuations? Cyclicality in infant mortality in India.* **Bhalotra, Sonia.** 2010, Journal of Development Economics, pp. 7-19.

5. *Aggregate income shocks and infant mortality in the developing world.* **Baird, Sarah, Jed Friedman, and Norbert Schady.** 2011, Review of Economics and statistics, pp. 847-856.

6. *Economic crises, maternal and infant mortality, low birth weight and enrollment rates: evidence from Argentina's downturns.* **Cruces, Guillermo, Pablo Glüzmann, and Luis Felipe López Calva.** 2012, World Development, pp. 303-314.

7. *How many infants likely died in Africa as a result of the 2008–2009 global financial crisis?* **Friedman, Jed, and Norbert Schady.** 2013, Health Economics , pp. 611-622.

8. *Effects of economic downturns on child mortality: a global economic analysis, 1981–2010.* **Maruthappu, Mahiben, Robert A. Watson, Johnathan Watkins, Thomas Zeltner, Rosalind Raine, and Rifat Atun.** 2017, BMJ global health.

9. *Routine childhood immunisation during the COVID-19 pandemic in Africa: a benefit–risk analysis of health benefits versus excess risk of SARS-CoV-2 infection.* **Abbas, Kaja, Simon R. Procter, Kevin van Zandvoort, Andrew Clark, Sebastian Funk, Tewodaj Mengistu, Dan Hogan et al.** 10, 2020, The Lancet Global Health, Vol. 8, pp. e1264-e1272.

10. *Potential impact of the COVID-19 pandemic on HIV, tuberculosis, and malaria in low-income and middle-income countries: a modelling study.* **Hogan, Alexandra B., Britta L. Jewell, Ellie Sherrard-Smith, Juan F. Vesga, Oliver J. Watson, Charles Whittaker, Arran Hamlet et al.** 10, 2020, The Lancet Global Health, Vol. 8, pp. e1132-e1141.

11. *Potential effects of disruption to HIV programmes in sub-Saharan Africa caused by COVID-19: results from multiple mathematical models.* **Jewell, Britta L., Edinah Mudimu, John Stover, Debra Ten Brink, Andrew N. Phillips, Jennifer A. Smith, Rowan Martin-Hughes et al.** 9, 2020, The Lancet HIV, Vol. 7, pp. e629-e640.

12. *The potential public health consequences of COVID-19 on malaria in Africa.* **Sherrard-Smith, Ellie, Alexandra B. Hogan, Arran Hamlet, Oliver J. Watson, Charlie Whittaker, Peter Winskill, Fatima Ali et al.** 1, 2020, Nature medicine, Vol. 26, pp. 1411-1416.

13. **Organization, World Health.** *Pulse survey on continuity of essential health services during the COVID-19 pandemic.* 2020.

14. *The impact of the COVID-19 pandemic on maternal and perinatal health: a scoping review.* **Kotlar, Bethany, Emily Gerson, Sophia Petrillo, Ana Langer, and Henning Tiemeier.** 1, 2021, Vol. 18.

15. *Early estimates of the indirect effects of the COVID-19 pandemic on maternal and child mortality in low-income and middle-income countries: a modelling study.* **Roberton, Timothy, Emily D. Carter, Victoria B. Chou, Angela R. Stegmuller, Bianca D. Jackson, Yvonne Tam, Talata Sawadogo-Lewis, and Neff Walker.** 7, 2020, The Lancet Global Health, Vol. 8, pp. e901-e908.

16. *Impact of COVID-19 pandemic response on uptake of routine immunizations in Sindh, Pakistan: an analysis of provincial electronic immunization registry data.* **Chandir, Subhash, Danya Arif Siddiqi, Mariam Mehmood, Hamidreza Setayesh, Muhammad Siddique, Amna Mirza, Riswana Soundardjee et al.** 45, 2020, Vaccine , Vol. 38, pp. 7146-7155.

17. *Child healthcare and immunizations in sub-Saharan Africa during the COVID-19 pandemic.* **Buonsenso, Danilo, Bianca Cinicola, Memenatu Ngaima Kallon, and Francesco Iodice.** Frontiers in pediatrics, p. 517.

18. *Access to primary healthcare during lockdown measures for COVID-19 in rural South Africa: an interrupted time series analysis.* **Siedner, Mark J., John D. Kraemer, Mark J. Meyer, Guy Harling, Thobeka Mngomezulu, Patrick Gabela, Siphephelo Dlamini et al.** 2020, BMJ open.

19. *Disruptions in maternal and child health service utilization service utilization during COVID-19: analysis from eight sub-Saharan African countries.* **Shapira, Gil, et al.** s.l. : Health Policy and Planning, 2021.

20. **Fund, International Monetary.** *World Economic Outlook, October 2020: A Long and Difficult Ascent.* . 2020.

21. **Christoph Lakner, Nishant Yonzandaniel Gerszon Mahlerr. Andres Castanesa and Aguilarhaoyu Wu.** Updated estimates of the impact of COVID-19 on global poverty: Looking back at 2020 and the outlook for 2021.

22. **Doerr, Sebastian, and Boris Hofmann.** *The recession-mortality nexus and Covid-19.* s.l. : Bank of International Settlements, 2020.

23. *Falling living standards during the COVID-19 crisis: Quantitative evidence from nine developing countries.* **Dennis Egger, Edward Miguel, Shana S. Warren, Ashish Shenoy, Elliott Collins, Dean Karlan, Doug Parkerson, A. Mushfiq Mobarak, Günther Fink, Christopher Udry, Michael Walker, Johaness Haushofer, Magdalena Larreboure, Susan Athey, Paula Lopez-Pena, Salim B.** 2021, Science Advances.

24. *Forecasts in times of crises.* **Eicher, Theo S., David J. Kuenzel, Chris Papageorgiou, and Charis Christofides.** 3, s.l. : International Journal of Forecasting, 2019, Vol. 35.

25. *Data quality and accuracy of United Nations population projections.* **Keilman, Nico.** 2, s.l. : Population Studies, Vol. 55.

Tables

Table 1: Estimated relationship between aggregate income shocks and infant mortality rate per 1,000 children, by World Bank country income groups

Low-income countries	Lower-middle-income countries	Upper-middle-income countries	Low- and middle-income countries
-47.85***	-23.73***	-16.08***	-23.12***
(17.71)	(5.50)	(6.80)	(9.38)

Source: authors' estimation using data from Demographic and Health surveys and World Development Indicators
Notes: Overall number of observed births is 5,273,350. The table presents coefficient estimates from regressions of infant mortality log per capita GDP with time trends and country fixed effects. Standard errors are presented in parentheses. There are four income groupings for countries; the country income groups follow the World Bank classification for fiscal year 2021.
* p<0.10, ** p<0.05, *** p<0.01.

Table 2: Projected excess infant deaths with 95% confidence intervals, by World Bank country income groups and regions

	Estimate	95% CI	Countries
Total	267,318	112,000 – 422,415	128
By income group:			
Low-income economies	65,628	18,013-113,241	29
Lower-middle income economies	158,638	86,646-230,628	46
Upper-middle income economies	42,942	7,340-78,544	53
By region:			
Sub-Saharan Africa	82,239	29,198-135,280	48
East Asia and Pacific	32,537	12,899-52,174	19
Europe and Central Asia	2,962	2,372-13,553	20
Latin America and the Caribbean	17,202	3,628-30,776	23
Middle East and North Africa	14,127	4,067-24,187	10
South Asia	113,141	59,836-166,446	8

Source: authors' projections based on estimated parameters presented in Table 1 and data from IMF World Economic Outlook and World Population Prospects.
Notes: The definitions of income groups and regions are based on the World Bank country group categorization for the 2021 fiscal year.

Appendix Table A1: Demographic and Health Surveys datasets used in the analysis

Low-income	Lower-middle income	Upper-middle income
Afghanistan 2015	Angola 2016	Albania 2009, 2018
Benin 1996, 2001, 2006, 2012, 2018	Bangladesh 1994, 1997, 2000, 2004, 2007, 2011, 2014	Armenia 2000, 2005, 2010, 2016
Burkina Faso 1993, 1999, 2003, 2010	Bolivia 1989, 1994, 1998, 2004, 2008	Azerbaijan 2006
Burundi 1987, 2011, 2017	Cambodia 2000, 2006, 2011, 2014	Brazil 1986, 1992, 1996
Central African Republic 1995	Cameroon 1991, 1998, 2004, 2011, 2018	Colombia 1986, 1990, 1995, 2000, 2005, 2010, 2016
DRC 2007, 2014	Comoros 1996, 2012	Dominican Republic 1986, 1991, 1996, 1999, 2002, 2007, 2013
Ethiopia 2000, 2005, 2011, 2016	Republic of Congo 2005, 2012	Ecuador 1987
Gambia 2013	Cote d'Ivoire 1994, 1999, 2012	Gabon 2001, 2012
Guinea 1999, 2005, 2012, 2018	Egypt 1989, 1993, 1996, 2003, 2005, 2008, 2014	Guatemala 1987, 1995, 1999, 2015
Haiti 1995, 2000, 2006, 2012, 2017	El Salvador 1985	Guyana 2009
Liberia 2007, 2013	Eswatini 2007	Jordan 1990, 1997, 2002, 2007, 2012, 2018
Madagascar 1992, 1997, 2004, 2009	Ghana 1988, 1994, 2003, 2008, 2014	Kazakhstan 1995, 1999
Malawi 1992, 2000, 2005, 2010, 2016	Honduras 2006, 2012	Maldives 2009, 2017
Mali 1987, 1996, 2001, 2006, 2013, 2018	India 1993, 1999, 2006, 2016	Mexico 1987
Mozambique 1997, 2004, 2011, 2015	Indonesia 1987, 1991, 1994, 1997, 2003, 2007, 2012, 2017	Namibia 1992, 2000, 2007, 2013
Nepal 1997, 2001, 2006, 2011, 2017	Kenya 1989, 1993, 1998, 2003, 2009, 2014	Paraguay 1990
Niger 1992, 1998, 2006, 2012	Kyrgyz Republic 1997, 2012	Peru 1986, 1992, 1996, 2000, 2004-2012*
Rwanda 1992, 2000, 2008, 2011, 2015	Lesotho 2005, 2010, 2014	
Sierra Leone 2008, 2013	Moldova 2005	
Tajikistan 2012, 2017	Morocco1987, 1992, 2004	
Tanzania 1999, 2005, 2012, 2016	Myanmar 2016	
Togo 1988, 1998, 2014	Nicaragua 1998, 2001	
Uganda 1989, 1995, 2001, 2006	Nigeria 1990, 2003, 2008, 2013, 2018	
Yemen 1992, 2013	Pakistan 1991, 2007, 2013, 2018	
	Papua New Guinea 2018	
	Philippines 1993, 1998, 2003, 2008, 2013, 2017	
	Sao Tome and Principe 2009	
	Senegal 1986, 1993, 1997, 2011, 2012-2018*	
	Sudan 1990	
	Timor Leste 2010, 2016	
	Tunisia 1988	
	Ukraine 2007	
	Uzbekistan 1996	
	Vietnam 1997, 2002	
	Zambia 1992, 1997, 2002, 2007, 2014, 2018	
	Zimbabwe 1989, 1994, 1999, 2006, 2011, 2015	

Notes: The years denote the timing of survey implementation in each country. Some surveys spanned over more than one calendar year. In these cases, the last year of the survey is indicated. For the analysis, retrospective birth histories are used to create birth and infant mortality data for the 11 years preceding each survey.
* Senegal and Peru had special continuous surveys. Peru had annual survey between 2004 and 2012 and Senegal completed annual surveys between 2012 to 2018.

Appendix Table A2: Projections of growth shortfall and excess infant mortality in lower- and middle-income countries

Country	Region [a]	Number of annual birth 2015-2020 (in thousands) [b]	WEO projections of 2020 growth [c]			Excess mortality projection		
			October 2019 projection	October 2020 projection	Growth Shortfall	estimate	95% lower bound	95% higher bound
Panel A: Lower Income Economies [a]								
Afghanistan	SAR	1205	3.5	-5.0	-8.5	4888	1342	8434
Benin	AFR	413	6.7	2.0	-4.7	930	255	1604
Burkina Faso	AFR	745	6.0	-2.0	-8.0	2852	783	4920
Burundi	AFR	433	0.5	-3.2	-3.7	775	213	1338
Central African Republic	AFR	165	5.0	-1.0	-5.9	468	128	807
Chad	AFR	648	5.4	-0.7	-6.1	1894	520	3267
Congo, Dem. Rep.	AFR	3434	3.9	-2.2	-6.0	9925	2724	17126
Eritrea	AFR	106	3.9	-0.6	-4.5	226	62	391
Ethiopia	AFR	3514	7.2	1.9	-5.3	8832	2424	15240
Gambia, The	AFR	87	6.4	-1.8	-8.2	343	94	591
Guinea	AFR	449	6.0	1.4	-4.5	970	266	1673
Guinea-Bissau	AFR	66	4.9	-2.9	-7.8	245	67	422
Haiti	LAC	271	1.2	-4.0	-5.2	674	185	1164
Liberia	AFR	158	1.6	-3.0	-4.6	345	95	596
Madagascar	AFR	852	5.3	-3.2	-8.5	3454	948	5960
Malawi	AFR	614	5.1	0.6	-4.5	1323	363	2283
Mali	AFR	787	5.0	-2.0	-7.0	2631	722	4540
Mozambique	AFR	1099	6.0	-0.5	-6.5	3441	944	5937
Nepal	SAR	562	6.3	0.0	-6.3	1681	461	2900
Niger	AFR	1023	6.1	0.5	-5.6	2717	746	4688
Rwanda	AFR	390	8.1	2.0	-6.1	1142	313	1970
Sierra Leone	AFR	255	4.7	-3.1	-7.7	945	260	1631
Somalia	AFR	622	3.2	-1.5	-4.7	1398	384	2412
South Sudan	AFR	386	8.2	4.1	-4.1	757	208	1306
Tajikistan	ECA	281	4.5	1.0	-3.5	470	129	811
Tanzania	AFR	2052	5.7	1.9	-3.8	3732	1024	6440
Togo	AFR	260	5.3	0.0	-5.3	659	181	1137
Uganda	AFR	1614	6.2	-0.3	-6.5	5022	1378	8666
Yemen, Rep.	MNA	865	2.0	-5.0	-7.0	2890	793	4987

Panel B: Lower-Middle Income Economies [a]								
Angola	AFR	1243	1.2	-4.0	-5.2	1523	832	2215
Bangladesh	SAR	2946	7.4	3.8	-3.6	2550	1393	3707
Bhutan	SAR	13	7.2	0.6	-6.6	21	11	30
Bolivia	LAC	247	3.8	-7.9	-11.7	685	374	996
Cabo Verde	AFR	11	5.0	-6.8	-11.7	30	16	43
Cambodia	EAP	366	6.8	-2.8	-9.5	828	452	1204
Cameroon	AFR	887	4.2	-2.8	-6.9	1461	798	2124
Comoros	AFR	26	4.2	-1.8	-6.1	38	21	55
Congo, Rep.	AFR	171	2.8	-7.0	-9.8	398	217	578
Côte d'Ivoire	AFR	890	7.3	1.8	-5.5	1161	634	1688
Djibouti	AFR	21	6.0	-1.0	-7.0	34	19	50
Egypt	MNA	2584	5.9	3.5	-2.3	1424	778	2070
El Salvador	LAC	118	2.3	-9.0	-11.3	315	172	458
Eswatini	AFR	30	0.5	-3.5	-4.0	29	16	41
Ghana	AFR	871	5.6	0.9	-4.7	968	529	1407
Honduras	LAC	207	3.5	-6.6	-10.1	496	271	721
India	SAR	24238	7.0	-10.3	-17.3	99642	54424	144860
Indonesia	EAP	4842	5.1	-1.5	-6.6	7549	4123	10975
Kenya	AFR	1469	6.0	1.0	-5.0	1743	952	2533
Kiribati	EAP	3	2.3	-1.1	-3.4	3	1	4
Kyrgyz Republic	ECA	155	3.4	-12.0	-15.4	566	309	823
Lao PDR	EAP	167	6.5	0.2	-6.3	250	136	363
Lesotho	AFR	57	-0.2	-4.8	-4.6	62	34	91
Mauritania	AFR	147	5.9	-3.2	-9.1	318	174	463
Micronesia, Fed. Sts.	EAP	3	0.8	-3.8	-4.6	3	2	4
Moldova	ECA	41	3.8	-4.5	-8.3	81	44	118
Mongolia	EAP	77	5.4	-2.0	-7.4	134	73	195
Morocco	MNA	682	3.7	-7.0	-10.7	1725	942	2508
Myanmar	EAP	948	6.3	2.0	-4.3	959	524	1395
Nicaragua	LAC	134	-0.8	-5.5	-4.7	151	82	219
Nigeria	AFR	7377	2.5	-4.3	-6.8	11904	6502	17306
Pakistan	SAR	5994	2.4	-0.4	-2.7	3891	2125	5656
Papua New Guinea	EAP	232	2.6	-3.3	-5.8	322	176	468
Philippines	EAP	2178	6.2	-8.3	-14.4	7466	4078	10855

Senegal	AFR	544	6.8	-0.7	-7.4	961	525	1397
Solomon Islands	EAP	21	2.9	-5.0	-7.9	39	21	57
Sudan	AFR	1339	-1.5	-8.4	-6.9	2182	1192	3172
São Tomé and Príncipe	AFR	7	3.5	-6.5	-10.0	16	9	23
Timor-Leste	EAP	37	5.0	-6.8	-11.8	105	57	152
Tunisia	MNA	204	2.4	-7.0	-9.5	458	250	666
Ukraine	ECA	426	3.0	-7.2	-10.2	1032	564	1500
Uzbekistan	ECA	703	6.0	0.7	-5.3	884	483	1285
Vanuatu	EAP	9	3.1	-8.3	-11.4	23	13	34
Vietnam	EAP	1610	6.5	1.6	-4.9	1872	1023	2722
Zambia	AFR	622	1.7	-4.8	-6.5	963	526	1400
Zimbabwe	AFR	442	2.7	-10.4	-13.1	1375	751	1999
Nigeria	AFR	7377	2.5	-4.3	-6.8	11904	832	2215
Pakistan	SAR	5994	2.4	-0.4	-2.7	3891	1393	3707
Papua New Guinea	EAP	232	2.6	-3.3	-5.8	322	11	30
Philippines	EAP	2178	6.2	-8.3	-14.4	7466	374	996
Senegal	AFR	544	6.8	-0.7	-7.4	961	16	43
Solomon Islands	EAP	21	2.9	-5.0	-7.9	39	452	1204
Sudan	AFR	1339	-1.5	-8.4	-6.9	2182	798	2124
São Tomé and Príncipe	AFR	7	3.5	-6.5	-10.0	16	21	55
Timor-Leste	EAP	37	5.0	-6.8	-11.8	105	217	578
Tunisia	MNA	204	2.4	-7.0	-9.5	458	634	1688
Ukraine	ECA	426	3.0	-7.2	-10.2	1032	19	50
Uzbekistan	ECA	703	6.0	0.7	-5.3	884	778	2070
Vanuatu	EAP	9	3.1	-8.3	-11.4	23	172	458
Vietnam	EAP	1610	6.5	1.6	-4.9	1872	16	41
Zambia	AFR	622	1.7	-4.8	-6.5	963	529	1407
Zimbabwe	AFR	442	2.7	-10.4	-13.1	1375	271	721
Panel C: Upper-Middle Income Economies [a]								
Albania	ECA	34	4.0	-7.5	-11.6	63	11	116
Algeria	MNA	1032	2.4	-5.5	-7.9	1305	223	2388
Argentina	LAC	755	-1.3	-11.8	-10.5	1276	218	2333
Armenia	ECA	42	4.8	-4.5	-9.3	62	11	114
Azerbaijan	ECA	169	2.1	-4.0	-6.1	167	28	305
Belarus	ECA	112	0.3	-3.0	-3.3	59	10	108

Belize	LAC	8	2.1	-16.0	-18.1	23	4	42
Bosnia and Herzegovina	ECA	27	2.6	-6.5	-9.1	40	7	74
Botswana	AFR	56	4.3	-9.6	-14.0	126	22	231
Brazil	LAC	2934	2.0	-5.8	-7.8	3700	632	6768
Bulgaria	ECA	63	3.2	-4.0	-7.2	73	13	134
China	EAP	16978	5.8	1.9	-4.0	10835	1852	19818
Colombia	LAC	739	3.6	-8.2	-11.8	1407	240	2573
Costa Rica	LAC	70	2.5	-5.5	-8.0	91	15	166
Dominican Republic	LAC	208	5.2	-6.0	-11.2	375	64	686
Ecuador	LAC	336	0.5	-11.0	-11.5	621	106	1135
Equatorial Guinea	AFR	43	-5.0	-6.0	-1.0	7	1	13
Fiji	EAP	19	3.0	-21.0	-24.0	73	13	134
Gabon	AFR	67	3.4	-2.7	-6.1	65	11	120
Georgia	ECA	54	4.8	-5.0	-9.8	86	15	157
Grenada	LAC	2	2.7	-11.8	-14.5	4	1	8
Guatemala	LAC	423	3.5	-2.0	-5.5	377	64	690
Guyana	LAC	16	85.6	26.2	-59.4	149	25	273
Iran	MNA	1552	0.0	-5.0	-5.0	1257	215	2298
Iraq	MNA	1104	4.7	-12.1	-16.7	2972	508	5436
Jamaica	LAC	47	1.0	-8.6	-9.6	73	13	134
Jordan	MNA	215	2.4	-5.0	-7.4	255	44	467
Kazakhstan	ECA	389	3.9	-2.7	-6.6	413	71	756
Lebanon	MNA	117	0.9	-25.0	-25.9	488	83	893
Libya	MNA	126	0.0	-66.7	-66.6	1353	231	2475
Malaysia	EAP	527	4.4	-6.0	-10.4	882	151	1613
Maldives	SAR	7	6.0	-18.6	-24.6	28	5	52
Mauritius	AFR	13	3.8	-14.2	-18.0	38	6	69
Mexico	LAC	2224	1.3	-9.0	-10.3	3670	627	6713
Montenegro	ECA	7	2.5	-12.0	-14.5	17	3	32
Namibia	AFR	70	1.6	-5.9	-7.4	83	14	153
North Macedonia	ECA	23	3.4	-5.4	-8.8	32	5	58
Paraguay	LAC	143	4.0	-4.0	-8.0	185	32	338
Peru	LAC	574	3.6	-13.9	-17.6	1621	277	2966
Romania	ECA	192	3.5	-4.8	-8.3	256	44	468
Russia	ECA	1858	1.9	-4.1	-6.0	1788	306	3271

Samoa	EAP	5	4.4	-5.0	-9.4	7	1	13
Serbia	ECA	84	4.0	-2.5	-6.5	87	15	160
South Africa	AFR	1185	1.1	-8.0	-9.1	1730	296	3165
Sri Lanka	SAR	339	3.5	-4.6	-8.1	441	75	806
St. Lucia	LAC	2	3.2	-16.9	-20.1	7	1	13
St. Vincent and the Grenadines	LAC	2	2.3	-7.0	-9.3	2	0	4
Suriname	LAC	11	2.5	-13.1	-15.6	27	5	49
Thailand	EAP	725	3.0	-7.1	-10.2	1183	202	2164
Tonga	EAP	3	3.7	-2.5	-6.2	3	0	5
Turkey	ECA	1318	3.0	-5.0	-8.0	1689	289	3089
Turkmenistan	ECA	139	6.0	1.8	-4.3	95	16	174
Venezuela, RB	LAC	528	-10.0	-25.0	-15.0	1273	218	2328

[a] The country classification into income and region groups follows the World Bank classification for fiscal year 2021. AFR = sub-Saharan Africa; EAP = East Asia and Pacific; ECA = European and Central Asia; LAC = Latin America and Caribbean; MNA = Middle East and North Africa SAR = South Asia;

[b] Number of births projected by the United Nations World Population Prospects 2019.

[c] Projections by the IMF World Economic Outlook for 2020.

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How many infants may have died in low- and middle-income countries in 2020 due to the economic contraction accompanying the COVID-19 pandemic? Mortality projections based on forecasted declines in economic growth

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How many infants may have died in low- and middle-income countries in 2020 due to the economic contraction accompanying the COVID-19 pandemic? Mortality projections based on forecasted declines in economic growth

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Abstract

Objectives: While COVID-19 has a relatively small direct impact on infant mortality, the pandemic is expected to indirectly increase mortality of this vulnerable group in low- and middle-income countries through its effects on the economy and health system performance. Previous studies projected indirect mortality by modelling how hypothesized disruptions in health services will affect health outcomes. We provide alternative projections, relying on modelling the relationship between aggregate income shocks and mortality.

Design: We construct a sample of 5.2 million births by pooling retrospective birth histories reported by women in Demographic and Health Surveys conducted in 83 low- and middle-income countries between 1985 and 2018. We employ regression models with country-specific fixed-effects and flexible time trends to estimate the impact of GDP per capita on infant mortality rate. We then use growth projections by the International Monetary Fund to predict the effect of the economic downturn in 2020 on infant mortality.

Results: We estimate 267,208 (112,000-422,415) excess infant deaths in 128 countries, corresponding to a 6.8% (2.8%-10.7%) increase in the total number of infant deaths expected in 2020.

Conclusions: The findings underscore the vulnerability of infants to the negative income shocks such as those imposed by the COVID-19 pandemic. While efforts towards prevention and treatment of COVID-19 remain paramount, the global community should also strengthen social safety nets and assure continuity of essential health services.

Strengths and limitations of this study

- Our study links GDP per capita data to an especially large dataset of 5.2 million retrospective birth histories reported in Demographic and Health Surveys (DHS) conducted in many low- and middle-income countries between 1985 and 2017.
- While previous projections of indirect COVID-19 mortality have been based on assumptions regarding the magnitude of health service disruptions, our estimates account for additional mechanisms, mainly increased household poverty.
- Our estimates may represent a lower bound of the actual excess mortality if the current economic downturn is accompanied by larger disruptions to the provision of essential health services relative to previous downturns.

- We estimate the short-term impact of GDP fluctuations on mortality while longer-term implications for mortality and other adverse outcomes may also arise.
- The analysis ascribes the difference between October 2019 and October 2020 economic growth projections for 2020 solely to the pandemic, even though some countries have also experienced other shocks, such as natural disasters or political crises that may affect national income levels.

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Introduction

Reducing morality risk in the wake of the COVID-19 pandemic is a paramount public concern. While direct mortality risk as a result of COVID-19 infection has garnered the majority of attention in global media and policy discussions, indirect mortality may be substantial. Health and social policies should not lose sight of excess indirect mortality caused by such factors as the interruption of essential health services and the general economic downturn brought on by the pandemic. This study attempts to quantify the expected indirect mortality over the pandemic period for one especially vulnerable sub-population – infants – by modeling the impact of projected economic decline on the likelihood of infant survival.

Studies from diverse settings find negligible direct mortality rates for children and infants due to COVID-19 (1). However, stringent containment measures and the ensuing economic downturn, as well as the need to reallocate health system resources towards pandemic response, have influenced many social determinants of mortality such as the ability to afford nutritious foods and to access essential health care. Unlike economic crises in high income countries, which appear to lower mortality (2), economic crises in low-income countries generally increase mortality among vulnerable groups, namely young children and the elderly. Earlier studies have documented a robust relationship between short-term fluctuation in aggregate income and all-cause infant mortality in low- and middle-income countries (3) (4) (5) (6) (7) (8).

At the very start of the COVID-19 pandemic, modelling exercises predicted that the interruption of essential health services will be severe (9) (10) (11) (12) (13) (14) and perhaps the world will experience 250,000 to 1.15 million young child deaths (15) in the first six months of the pandemic. Recent studies indicate that barriers to access essential health care in low- and middle-income are not just a theoretical concern documenting, for example, disruptions in immunization services in Pakistan and Sierra Leone (16) (17), and access to primary care in sub-Saharan Africa (18) (19). At the same time, the global economy is expected to contract 4.9% in the first year of the pandemic (20) and the global poverty headcount is projected to increase by 120 million people (21). Based on historical data, this economic decline is likely to be associated with higher mortality in excess of COVID-19 fatalities (22), especially in developing economies, and will create food insecurity (23) and lower the affordability among vulnerable households of key goods and services necessary for child survival.

In this study, we estimate the impact of the economic downturn on infant mortality by modelling the relationship between GDP fluctuations and infant mortality, following the approach of Baird et al (2011) (5). We link GDP per capita data to 5.2 million retrospective birth histories reported in 83 Demographic and Health Surveys (DHS) conducted in low- and middle-income countries between 1985 and 2017. Then, we use growth projections by International Monetary Fund (IMF) World Economic Outlook (WEO) to predict the effect of the economic downturn in 2020 on infant mortality.

Data and Methods

To estimate the impact of changes in aggregate income on infant mortality, we rely on two sources of data. Data on GDP per capita is taken from the World Development Indicators. We use values adjusted for purchasing power parity, corresponding to 2011 US dollars. Data on infant mortality are constructed from retrospective birth history reports in all Demographic and Health Surveys conducted in 83 low- and middle-income countries between 1985 and 2018. The surveys used in the analysis are listed in Table A1 in the appendix. The combined sample totals 5.2 million births, of which 27 and 55 percent are from low- and lower-middle income countries. Over the full period of analysis, the sample's infant mortality rate per 1000 births is 85, 61 and 37 for low-, lower-middle and upper-middle income countries respectively.

We estimate the relation between aggregate income change and infant mortality with the following framework:

$$D_{ict} = \alpha_c + \beta logGDP_{ct} + \gamma_{1c}t_{ct} + \gamma_{2c}t_{ct}^2 + \gamma_{3c}t_{ct}^3 + \varepsilon_{ict}$$

$\boldsymbol{D_{ict}}$ is a binary indicator taking the value 1 if child i in country c died in the first 12 months of life during year t. $logGDP$ is the natural logarithm of per capita GDP, and $\varepsilon_{iact}$is the error term. The α and γ coefficients identify country-specific fixed effects and a country-specific cubic time trend, respectively. Standard errors are clustered at the country level. β is the coefficient of interest, describing the relationship between aggregate income shocks and infant mortality. We estimate this semi-elasticity of infant mortality to aggregate income decline separately by country income level, as classified by the World Bank 2020 income groups, as well as overall. Low-income economies are defined by a gross national income (GNI) per capita of less than 1,035 USD in 2019. Lower middle-income economies are defined by a GNI between 1,036 and 4,045 USD and the range for upper middle-income economies is between 4,046 and 12,535 USD. To explore the robustness of the findings, both we and Baird et al. (2011) (5) find appreciably similar results with linear or quadratic time trends, as well as alternative recall periods for births (5 or 15 years as opposed to the default 10 years).

As a projection of the aggregate income shock in each country, we compare growth predictions for the same calendar period made before and then during the pandemic. Specifically, we use the IMF WEO 2020 growth rates projected in October 2019 and in October 2020. We define the difference between the two projections as the growth shortfall that is likely attributed to the pandemic and the ensuing economic crisis. Between October 2019 and October 2020, the IMF revised downwards the growth projections for all countries. The average shortfall for lower- and middle-income countries is 9.3 percent. The average projected shortfall in low-income countries, 5.9 percent, is less than half of the projected average shortfall in upper-middle income countries, 12.5 percent.

To calculate the number of excess infant deaths that were likely caused by the pandemic in each country, we multiply the projected growth shortfalls with the β coefficient from the regression specification above. We then multiply by the projected number of births in each country, taken from the United Nation's World Population Prospects 2019. The total number of births are projected for the five-year period 2015-2020 and we assume equal proportion of births for each year. (The projections are available at population.un.org/wpp.)

Patient and Public Involvement

The study presents analysis of secondary data. There was no patient and public involvement.

Results

Estimation of the GDP-Mortality relationship

The regression coefficient estimates are presented in Table 1. A 1% decrease in GDP per capita is associated with a 0.23 increase in infant mortality per 1,000 children born in low- and middle-income countries. These estimates vary substantially by income group. A 1% decrease in per capita GDP is associated with increases of 0.48, 0.24 and 0.16 in infant mortality per 1,000 children born in low- lower-middle- and upper-middle-income countries, respectively.

Our estimate for the relationship between GDP and infant mortality is significantly lower than the estimate presented in Baird, Friedman and Schady (2011), using the same specification (5). This previous analysis estimated that a 1% decrease in GDP per capita is associated with a 0.40 increase in infant mortality per 1000 children born in low- and middle-income countries. Two things might drive this difference. First, we have a different composition of countries given that more DHS datasets are available. Our analysis includes 83 countries relative to 59 in the earlier paper. Second, resiliency to income shocks may have improved over time through increased household incomes and more developed health systems.

Projection of excess infant mortality in 2020

In Table 2, we report the estimated excess infant mortality in 128 low- and middle-income countries, along with 95% confidence interval around the estimate. The results by income group and region presented in Table 2 are aggregations of the country level projections presented in Appendix Table A2. In total, we estimate 267,208 (112,000-422,415) excess infant deaths in lower- and middle-income countries due to the growth shortfall in 2020. Most of the excess mortality is estimated to occur in the 46 lower-middle income countries, even though the income-mortality semi-elasticity in low-income countries (LIC) is almost twice the size of that in lower-middle income countries (LMIC). This is explained both by the fact that there are more countries and more populous countries in the LMIC group and because the IMF projects larger growth shortfalls in that group. It is worth noting than more than a third of the excess infant mortality is projected to be in India (99,642). India has the highest number of annual births (24,238,000) as well as a particularly large projected economic shortfall of -17.3%. Because of this, South Asia is the region with the highest expected excess infant mortality although there are only 8 countries included in the analysis. Nigeria and China are a distant second and third with projected excess infant deaths of 11,904 and 10,835.

To benchmark our projections of excess infant deaths, we assess the percentage increase in infant mortality these additional deaths represent. To that end, we calculate the expected infant mortality in the absence of the pandemic for the 128 countries. According to the World Bank's World Development Indicators, estimated infant mortality rates in low-, lower-middle, and upper-middle countries were 48, 37 and 11 deaths per 1000 live births in 2019. We multiply these rates by the annual number of births in each country to forecast a total of 3,953,466 deaths. Assuming that infant mortality rate in 2020 would have been similar to that in 2019 if the COVID-19 outbreak hasn't occurred, the excess deaths we project correspond to an increase of 6.8 (2.8-10.7) percent in the total number of expected infant deaths.

Discussion

In this study, we have assessed the potential impact of the 2020 economic downturn caused by the COVID-19 pandemic on infant mortality – we estimate almost 270,000 excess infant deaths in the 12 months following the pandemic start. A useful comparison point to this estimate is the 28,000 to 50,000 excess infant deaths estimated for Africa after the financial crisis in 2009 (7). Our Africa estimate in 2020 is 82,239 (37,858-126,620) infant deaths. This higher projection reflects the larger estimated GDP shortfalls. Several mechanisms are likely driving this increase in mortality among children aged 0-1: impoverishment at the household level will lead to worse nutrition and care practices for infants and reduced ability to access health services, while the economic crisis might also affect the supply and quality of services offered by the health systems (19). It is difficult to compare our estimates with other projections focusing on health system disruption as the main driver as the methodology, the age ranges, and the time period are different. The most comparable study, with a focus on child mortality, predicts 253,500 to 1,157,000 additional under-5 child deaths over the first six months of the pandemic, depending on the scenario severity (15).

Our estimates of excess infant mortality are not additional to previous projections but serve as an alternative. Our reduced form approach yields estimates that already incorporate at least some consequences of reduced utilization of health services, i.e those reductions that have historically arose during severe economic downturns. Our estimates also directly account for other mechanisms, mainly increased poverty. As past economic crises were not driven by a pandemic, it is possible that the world will experience a higher indirect mortality shock than implied by the historic income-mortality semi-elasticity if the current economic downturn is accompanied by more severe disruptions to the supply of effective health services. Therefore, our projections may provide a lower bound of actual indirect mortality. On the other hand, the projections reported in this paper ascribe the difference between the WEO October 2019 and October 2020 economic growth projections for 2020 solely to the pandemic, even though some countries have also experienced other shocks, such as natural disasters or political crises.

Regarding limitations of the analysis, one refinement of our estimation approach would consider the relevant expenditure categories that directly determine the production of child health, rather than overall expenditure as captured in GDP. Relevant expenditure categories include public health sector spending, private spending on health and nutrition, foreign assistance in the form of health aid, and public and private spending on related sectors and services such as water and sanitation. It is these components of GDP that are more directly tied to child survival and would likely exhibit a more predictive relationship to infant mortality than overall GDP exhibits. Unfortunately, this more granular data does not exist in a systematic and standardized form for the countries and time periods considered, nor are there standard future projections of such components. Therefore, we follow the existent literature and explore the relation between a widespread summary measures of national economic output, GDP, and infant survival.

An extension of our approach may also consider country characteristics that likely mediate the GDP-mortality relation, including measures of economic inequality. Infant mortality in more unequal countries is likely more vulnerable to economic contractions. However, here again, we do not have the necessary annual data to easily include a summary inequality measure such as the Gini Coefficient within our estimation framework. The Demographic and Health Surveys allow us to construct annual birth and mortality indicators from retrospective reports of fertility yet do not include per capita consumption or wealth status for the same years. Standard cross-country datasets such as PovCalNet (iresearch.worldbank.org/PovcalNet/index.htm) update the national Gini coefficient only on a sporadic basis. For example the Gini estimate for India is only updated for the years 1987, 1993, 2004, 2009, and 2011.

Another limitation of our analysis is that it relies on retrospective birth histories in Demographic and Health Surveys. In the absence of comprehensive and robust vital registration statistics in most of the countries included in this analysis, this is likely the most comprehensive data source available. However, such household survey data can be affected by recall bias, especially for birth and deaths occurring long before the survey date. For this reason, we have explored the stability of estimates to alternative birth recall periods and find appreciably similar results. Another limitation is that we only consider the short-term impact of GDP fluctuations on mortality while longer-term consequences might also exist. Longer-term impacts on the number of infant deaths could also occur through changes in fertility behavior but should not affect our projections for 2020. Although COVID-19 was first detected in the end of 2019, the outbreak was declared a pandemic only in March 2020. If there were impacts on fertility, they would impact births and infant mortality in 2021. Finally, economic contractions in high-income countries might reduce foreign aid to lower-income countries which in turn can increase mortality (24). If declining aid affects future GDP, our model does not account for such mechanisms as we assume that a country's infant mortality rate is only affected by its (own) contemporaneous GDP.

Regarding the reported confidence intervals for projected excess infant deaths in Table 2, note that these bounds may be regarded as conservative. This is because we first apply the 5th percentile lower bound and then the 95th percentile upper bound estimate of the mortality semi-elasticity to the projected growth contractions for all countries in order to estimate the bounds. This exercise implicitly imposes a perfect correlation of semi-elasticities across countries. If instead, each country receives its own independent draw from the distribution of semi-elasticities then there will be significantly tighter confidence bounds, at least in expectation.

On the other hand, there may also be forecast error in either the country-level economic growth projections or in the projections of number of births. These potential errors are not directly modeled. Previous literature suggests these forecast errors have an expected mean of zero, with most deviations from forecast on the order of plus/minus one percentage point of economic growth or plus/minus three percent of total births (25) (26). To explore further the role of uncertainty in economic and demographic projections, we consider Monte Carlo simulations that model country-specific growth and birth projections with a slightly larger anticipated degree of error. Specifically, we simulate a draw for each country from growth projections that are uniformly distributed around the projection at +- 1.5 percentage points and draws for the birth projection that are uniformly distributed around the projection at +- 4 percent. After 10,000 simulations we obtain a 95% CI of total excess deaths to be (251588, 283106). Substantially narrower than the reported CI of (112000, 422415). This suggests that uncertainty in the true value of the growth-IMR semi-elasticity is the most influential parameter driving uncertainty in the projected total number of indirect infant deaths.

Regardless of the exact number of projected deaths, the large number of excess infant deaths estimated in our analysis underscores the vulnerability of this age group to negative aggregate income shocks such as those induced by the COVID-19 pandemic. While we focused on the 0-1 age group, our estimates are suggestive of other vulnerabilities not directly attributable to COVID-19 among other segments of the population such as children aged 1-5, pregnant women, and the elderly. As countries, health systems, and the wider global community continue efforts to prevent and treat COVID-19, we should also consider resources to stabilize health systems and strengthen social safety nets in order to mitigate the human, social, and economic consequences of the pandemic and related lockdown policies.

Declaration of interests

We declare no competing interests.

Funding

This study did not require funding.

Data availability

Requests to access the data can be submitted on the Demographic and Health Surveys Program at dhsprogram.com.

Ethics Statement

Ethics approval was not sought as the study presents results of an analysis of secondary data and does not involve human participants.

Contributor Statement

DdW, JF and GS contributed to the conceptualization, design of the methodology and the writing. GS conducted the formal analysis and JF and GS validated the results.

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References

1. *Assessing the age specificity of infection fatality rates for COVID-19: systematic review, meta-analysis, and public policy implications.* **Levin, Andrew T., William P. Hanage, Nana Owusu-Boaitey, Kensington B. Cochran, Seamus P. Walsh, and Gideon Meyerowitz-Katz.** 2020, European journal of epidemiology, pp. 1-16.

2. *Health effects of economic crises.* **Ruhm, Christopher J.** 2016, Health Economics, pp. 6-24.

3. *Wealthier is Healthier.* **Pritchett, Lant, and Lawrence H. Summers.** 1996, Journal of Human Resources, pp. 841-868.

4. *Fatal fluctuations? Cyclicality in infant mortality in India.* **Bhalotra, Sonia.** 2010, Journal of Development Economics, pp. 7-19.

5. *Aggregate income shocks and infant mortality in the developing world.* **Baird, Sarah, Jed Friedman, and Norbert Schady.** 2011, Review of Economics and statistics, pp. 847-856.

6. *Economic crises, maternal and infant mortality, low birth weight and enrollment rates: evidence from Argentina's downturns.* **Cruces, Guillermo, Pablo Glüzmann, and Luis Felipe López Calva.** 2012, World Development, pp. 303-314.

7. *How many infants likely died in Africa as a result of the 2008–2009 global financial crisis?* **Friedman, Jed, and Norbert Schady.** 2013, Health Economics , pp. 611-622.

8. *Effects of economic downturns on child mortality: a global economic analysis, 1981–2010.* **Maruthappu, Mahiben, Robert A. Watson, Johnathan Watkins, Thomas Zeltner, Rosalind Raine, and Rifat Atun.** 2017, BMJ global health.

9. *Routine childhood immunisation during the COVID-19 pandemic in Africa: a benefit–risk analysis of health benefits versus excess risk of SARS-CoV-2 infection.* **Abbas, Kaja, Simon R. Procter, Kevin van Zandvoort, Andrew Clark, Sebastian Funk, Tewodaj Mengistu, Dan Hogan et al.** 10, 2020, The Lancet Global Health, Vol. 8, pp. e1264-e1272.

10. *Potential impact of the COVID-19 pandemic on HIV, tuberculosis, and malaria in low-income and middle-income countries: a modelling study.* **Hogan, Alexandra B., Britta L. Jewell, Ellie Sherrard-Smith, Juan F. Vesga, Oliver J. Watson, Charles Whittaker, Arran Hamlet et al.** 10, 2020, The Lancet Global Health, Vol. 8, pp. e1132-e1141.

11. *Potential effects of disruption to HIV programmes in sub-Saharan Africa caused by COVID-19: results from multiple mathematical models.* **Jewell, Britta L., Edinah Mudimu, John Stover, Debra Ten Brink, Andrew N. Phillips, Jennifer A. Smith, Rowan Martin-Hughes et al.** 9, 2020, The Lancet HIV, Vol. 7, pp. e629-e640.

12. *The potential public health consequences of COVID-19 on malaria in Africa.* **Sherrard-Smith, Ellie, Alexandra B. Hogan, Arran Hamlet, Oliver J. Watson, Charlie Whittaker, Peter Winskill, Fatima Ali et al.** 1, 2020, Nature medicine, Vol. 26, pp. 1411-1416.

13. **Organization, World Health.** *Pulse survey on continuity of essential health services during the COVID-19 pandemic.* 2020.

14. *The impact of the COVID-19 pandemic on maternal and perinatal health: a scoping review.* **Kotlar, Bethany, Emily Gerson, Sophia Petrillo, Ana Langer, and Henning Tiemeier.** 1, s.l. : Reproductive Health, 2021, Vol. 18.

15. *Early estimates of the indirect effects of the COVID-19 pandemic on maternal and child mortality in low-income and middle-income countries: a modelling study.* **Roberton, Timothy, Emily D. Carter, Victoria B. Chou, Angela R. Stegmuller, Bianca D. Jackson, Yvonne Tam, Talata Sawadogo-Lewis, and Neff Walker.** 7, 2020, The Lancet Global Health, Vol. 8, pp. e901-e908.

16. *Impact of COVID-19 pandemic response on uptake of routine immunizations in Sindh, Pakistan: an analysis of provincial electronic immunization registry data.* **Chandir, Subhash, Danya Arif Siddiqi, Mariam Mehmood, Hamidreza Setayesh, Muhammad Siddique, Amna Mirza, Riswana Soundardjee et al.** 45, 2020, Vaccine , Vol. 38, pp. 7146-7155.

17. *Child healthcare and immunizations in sub-Saharan Africa during the COVID-19 pandemic.* **Buonsenso, Danilo, Bianca Cinicola, Memenatu Ngaima Kallon, and Francesco Iodice.** s.l. : Frontiers in Perdiatrics, 2020, Frontiers in pediatrics, p. 517.

18. *Access to primary healthcare during lockdown measures for COVID-19 in rural South Africa: an interrupted time series analysis.* **Siedner, Mark J., John D. Kraemer, Mark J. Meyer, Guy Harling, Thobeka Mngomezulu, Patrick Gabela, Siphephelo Dlamini et al.** 2020, BMJ open.

19. *Disruptions in maternal and child health service utilization service utilization during COVID-19: analysis from eight sub-Saharan African countries.* **Shapira, Gil, et al.** s.l. : Health Policy and Planning, 2021.

20. **Fund, International Monetary.** *World Economic Outlook, October 2020: A Long and Difficult Ascent.* . 2020.

21. **Christoph Lakner, Nishant Yonzandaniel Gerszon Mahlerr. Andres Castanesa and Aguilarhaoyu Wu.** Updated estimates of the impact of COVID-19 on global poverty: Looking back at 2020 and the outlook for 2021.

22. **Doerr, Sebastian, and Boris Hofmann.** *The recession-mortality nexus and Covid-19.* s.l. : Bank of International Settlements, 2020.

23. *Falling living standards during the COVID-19 crisis: Quantitative evidence from nine developing countries.* **Dennis Egger, Edward Miguel, Shana S. Warren, Ashish Shenoy, Elliott Collins, Dean Karlan, Doug Parkerson, A. Mushfiq Mobarak, Günther Fink, Christopher Udry, Michael Walker, Johaness Haushofer, Magdalena Larreboure, Susan Athey, Paula Lopez-Pena, Salim B.** 6, 2021, Science Advances, Vol. 7.

24. *COVID-19, economic impact and child mortality: A global concern.* **Kabir, Mahvish, Muhammad Arif Nadeem Saqib, Muhammad Zaid, Haroon Ahmed, and Muhammad Sohail Afzal.** 7, 2020, Clinical Nutrition, Vol. 37.

25. *Forecasts in times of crises.* **Eicher, Theo S., David J. Kuenzel, Chris Papageorgiou, and Charis Christofides.** 3, s.l. : International Journal of Forecasting, 2019, Vol. 35.

26. *Data quality and accuracy of United Nations population projections.* **Keilman, Nico.** 2, s.l. : Population Studies, Vol. 55.

Tables

Table 1: Estimated relationship between aggregate income shocks and infant mortality rate per 1,000 children, by World Bank country income groups

Low-income countries	Lower-middle-income countries	Upper-middle-income countries	Low- and middle-income countries
-47.85***	-23.73***	-16.08***	-23.12***
(17.71)	(5.50)	(6.80)	(9.38)

Source: authors' estimation using data from Demographic and Health surveys and World Development Indicators
Notes: Overall number of observed births is 5,273,350. The table presents coefficient estimates from regressions of infant mortality log per capita GDP with time trends and country fixed effects. Standard errors are presented in parentheses. There are four income groupings for countries; the country income groups follow the World Bank classification for fiscal year 2021.
* p<0.10, ** p<0.05, *** p<0.01.

Table 2: Projected excess infant deaths with 95% confidence intervals, by World Bank country income groups and regions

	Estimate	95% CI	Countries
Total	267,318	112,000 – 422,415	128
By income group:			
Low-income economies	65,628	18,013-113,241	29
Lower-middle income economies	158,638	86,646-230,628	46
Upper-middle income economies	42,942	7,340-78,544	53
By region:			
Sub-Saharan Africa	82,239	29,198-135,280	48
East Asia and Pacific	32,537	12,899-52,174	19
Europe and Central Asia	2,962	2,372-13,553	20
Latin America and the Caribbean	17,202	3,628-30,776	23
Middle East and North Africa	14,127	4,067-24,187	10
South Asia	113,141	59,836-166,446	8

Source: authors' projections based on estimated parameters presented in Table 1 and data from IMF World Economic Outlook and World Population Prospects.
Notes: The definitions of income groups and regions are based on the World Bank country group categorization for the 2021 fiscal year.

Appendix Table A1: Demographic and Health Surveys datasets used in the analysis

Low-income	Lower-middle income	Upper-middle income
Afghanistan 2015 Benin 1996, 2001, 2006, 2012, 2018 Burkina Faso 1993, 1999, 2003, 2010 Burundi 1987, 2011, 2017 Central African Republic 1995 DRC 2007, 2014 Ethiopia 2000, 2005, 2011, 2016 Gambia 2013 Guinea 1999, 2005, 2012, 2018 Haiti 1995, 2000, 2006, 2012, 2017 Liberia 2007, 2013 Madagascar 1992, 1997, 2004, 2009 Malawi 1992, 2000, 2005, 2010, 2016 Mali 1987, 1996, 2001, 2006, 2013, 2018 Mozambique 1997, 2004, 2011, 2015 Nepal 1997, 2001, 2006, 2011, 2017 Niger 1992, 1998, 2006, 2012 Rwanda 1992, 2000, 2008, 2011, 2015 Sierra Leone 2008, 2013 Tajikistan 2012, 2017 Tanzania 1999, 2005, 2012, 2016 Togo 1988, 1998, 2014 Uganda 1989, 1995, 2001, 2006 Yemen 1992, 2013	Angola 2016 Bangladesh 1994, 1997, 2000, 2004, 2007, 2011, 2014 Bolivia 1989, 1994, 1998, 2004, 2008 Cambodia 2000, 2006, 2011, 2014 Cameroon 1991, 1998, 2004, 2011, 2018 Comoros 1996, 2012 Republic of Congo 2005, 2012 Cote d'Ivoire 1994, 1999, 2012 Egypt 1989, 1993, 1996, 2003, 2005, 2008, 2014 El Salvador 1985 Eswatini 2007 Ghana 1988, 1994, 2003, 2008, 2014 Honduras 2006, 2012 India 1993, 1999, 2006, 2016 Indonesia 1987, 1991, 1994, 1997, 2003, 2007, 2012, 2017 Kenya 1989, 1993, 1998, 2003, 2009, 2014 Kyrgyz Republic 1997, 2012 Lesotho 2005, 2010, 2014 Moldova 2005 Morocco1987, 1992, 2004 Myanmar 2016 Nicaragua 1998, 2001 Nigeria 1990, 2003, 2008, 2013, 2018 Pakistan 1991, 2007, 2013, 2018 Papua New Guinea 2018 Philippines 1993, 1998, 2003, 2008, 2013, 2017 Sao Tome and Principe 2009 Senegal 1986, 1993, 1997, 2011, 2012-2018* Sudan 1990 Timor Leste 2010, 2016 Tunisia 1988 Ukraine 2007 Uzbekistan 1996 Vietnam 1997, 2002 Zambia 1992, 1997, 2002, 2007, 2014, 2018 Zimbabwe 1989, 1994, 1999, 2006, 2011, 2015	Albania 2009, 2018 Armenia 2000, 2005, 2010, 2016 Azerbaijan 2006 Brazil 1986, 1992, 1996 Colombia 1986, 1990, 1995, 2000, 2005, 2010, 2016 Dominican Republic 1986, 1991, 1996, 1999, 2002, 2007, 2013 Ecuador 1987 Gabon 2001, 2012 Guatemala 1987, 1995, 1999, 2015 Guyana 2009 Jordan 1990, 1997, 2002, 2007, 2012, 2018 Kazakhstan 1995, 1999 Maldives 2009, 2017 Mexico 1987 Namibia 1992, 2000, 2007, 2013 Paraguay 1990 Peru 1986, 1992, 1996, 2000, 2004-2012*

Notes: The years denote the timing of survey implementation in each country. Some surveys spanned over more than one calendar year. In these cases, the last year of the survey is indicated. For the analysis, retrospective birth histories are used to create birth and infant mortality data for the 11 years preceding each survey.
* Senegal and Peru had special continuous surveys. Peru had annual survey between 2004 and 2012 and Senegal completed annual surveys between 2012 to 2018.

Appendix Table A2: Projections of growth shortfall and excess infant mortality in lower- and middle-income countries

Country	Region [a]	Number of annual birth 2015-2020 (in thousands) [b]	WEO projections of 2020 growth [c]			Excess mortality projection		
			October 2019 projection	October 2020 projection	Growth Shortfall	estimate	95% lower bound	95% higher bound
Panel A: Lower Income Economies [a]								
Afghanistan	SAR	1205	3.5	-5.0	-8.5	4888	1342	8434
Benin	AFR	413	6.7	2.0	-4.7	930	255	1604
Burkina Faso	AFR	745	6.0	-2.0	-8.0	2852	783	4920
Burundi	AFR	433	0.5	-3.2	-3.7	775	213	1338
Central African Republic	AFR	165	5.0	-1.0	-5.9	468	128	807
Chad	AFR	648	5.4	-0.7	-6.1	1894	520	3267
Congo, Dem. Rep.	AFR	3434	3.9	-2.2	-6.0	9925	2724	17126
Eritrea	AFR	106	3.9	-0.6	-4.5	226	62	391
Ethiopia	AFR	3514	7.2	1.9	-5.3	8832	2424	15240
Gambia, The	AFR	87	6.4	-1.8	-8.2	343	94	591
Guinea	AFR	449	6.0	1.4	-4.5	970	266	1673
Guinea-Bissau	AFR	66	4.9	-2.9	-7.8	245	67	422
Haiti	LAC	271	1.2	-4.0	-5.2	674	185	1164
Liberia	AFR	158	1.6	-3.0	-4.6	345	95	596
Madagascar	AFR	852	5.3	-3.2	-8.5	3454	948	5960
Malawi	AFR	614	5.1	0.6	-4.5	1323	363	2283
Mali	AFR	787	5.0	-2.0	-7.0	2631	722	4540
Mozambique	AFR	1099	6.0	-0.5	-6.5	3441	944	5937
Nepal	SAR	562	6.3	0.0	-6.3	1681	461	2900
Niger	AFR	1023	6.1	0.5	-5.6	2717	746	4688
Rwanda	AFR	390	8.1	2.0	-6.1	1142	313	1970
Sierra Leone	AFR	255	4.7	-3.1	-7.7	945	260	1631
Somalia	AFR	622	3.2	-1.5	-4.7	1398	384	2412
South Sudan	AFR	386	8.2	4.1	-4.1	757	208	1306
Tajikistan	ECA	281	4.5	1.0	-3.5	470	129	811
Tanzania	AFR	2052	5.7	1.9	-3.8	3732	1024	6440
Togo	AFR	260	5.3	0.0	-5.3	659	181	1137
Uganda	AFR	1614	6.2	-0.3	-6.5	5022	1378	8666
Yemen, Rep.	MNA	865	2.0	-5.0	-7.0	2890	793	4987

Panel B: Lower-Middle Income Economies [a]								
Angola	AFR	1243	1.2	-4.0	-5.2	1523	832	2215
Bangladesh	SAR	2946	7.4	3.8	-3.6	2550	1393	3707
Bhutan	SAR	13	7.2	0.6	-6.6	21	11	30
Bolivia	LAC	247	3.8	-7.9	-11.7	685	374	996
Cabo Verde	AFR	11	5.0	-6.8	-11.7	30	16	43
Cambodia	EAP	366	6.8	-2.8	-9.5	828	452	1204
Cameroon	AFR	887	4.2	-2.8	-6.9	1461	798	2124
Comoros	AFR	26	4.2	-1.8	-6.1	38	21	55
Congo, Rep.	AFR	171	2.8	-7.0	-9.8	398	217	578
Côte d'Ivoire	AFR	890	7.3	1.8	-5.5	1161	634	1688
Djibouti	AFR	21	6.0	-1.0	-7.0	34	19	50
Egypt	MNA	2584	5.9	3.5	-2.3	1424	778	2070
El Salvador	LAC	118	2.3	-9.0	-11.3	315	172	458
Eswatini	AFR	30	0.5	-3.5	-4.0	29	16	41
Ghana	AFR	871	5.6	0.9	-4.7	968	529	1407
Honduras	LAC	207	3.5	-6.6	-10.1	496	271	721
India	SAR	24238	7.0	-10.3	-17.3	99642	54424	144860
Indonesia	EAP	4842	5.1	-1.5	-6.6	7549	4123	10975
Kenya	AFR	1469	6.0	1.0	-5.0	1743	952	2533
Kiribati	EAP	3	2.3	-1.1	-3.4	3	1	4
Kyrgyz Republic	ECA	155	3.4	-12.0	-15.4	566	309	823
Lao PDR	EAP	167	6.5	0.2	-6.3	250	136	363
Lesotho	AFR	57	-0.2	-4.8	-4.6	62	34	91
Mauritania	AFR	147	5.9	-3.2	-9.1	318	174	463
Micronesia, Fed. Sts.	EAP	3	0.8	-3.8	-4.6	3	2	4
Moldova	ECA	41	3.8	-4.5	-8.3	81	44	118
Mongolia	EAP	77	5.4	-2.0	-7.4	134	73	195
Morocco	MNA	682	3.7	-7.0	-10.7	1725	942	2508
Myanmar	EAP	948	6.3	2.0	-4.3	959	524	1395
Nicaragua	LAC	134	-0.8	-5.5	-4.7	151	82	219
Nigeria	AFR	7377	2.5	-4.3	-6.8	11904	6502	17306
Pakistan	SAR	5994	2.4	-0.4	-2.7	3891	2125	5656
Papua New Guinea	EAP	232	2.6	-3.3	-5.8	322	176	468
Philippines	EAP	2178	6.2	-8.3	-14.4	7466	4078	10855

Senegal	AFR	544	6.8	-0.7	-7.4	961	525	1397
Solomon Islands	EAP	21	2.9	-5.0	-7.9	39	21	57
Sudan	AFR	1339	-1.5	-8.4	-6.9	2182	1192	3172
São Tomé and Príncipe	AFR	7	3.5	-6.5	-10.0	16	9	23
Timor-Leste	EAP	37	5.0	-6.8	-11.8	105	57	152
Tunisia	MNA	204	2.4	-7.0	-9.5	458	250	666
Ukraine	ECA	426	3.0	-7.2	-10.2	1032	564	1500
Uzbekistan	ECA	703	6.0	0.7	-5.3	884	483	1285
Vanuatu	EAP	9	3.1	-8.3	-11.4	23	13	34
Vietnam	EAP	1610	6.5	1.6	-4.9	1872	1023	2722
Zambia	AFR	622	1.7	-4.8	-6.5	963	526	1400
Zimbabwe	AFR	442	2.7	-10.4	-13.1	1375	751	1999
Nigeria	AFR	7377	2.5	-4.3	-6.8	11904	832	2215
Pakistan	SAR	5994	2.4	-0.4	-2.7	3891	1393	3707
Papua New Guinea	EAP	232	2.6	-3.3	-5.8	322	11	30
Philippines	EAP	2178	6.2	-8.3	-14.4	7466	374	996
Senegal	AFR	544	6.8	-0.7	-7.4	961	16	43
Solomon Islands	EAP	21	2.9	-5.0	-7.9	39	452	1204
Sudan	AFR	1339	-1.5	-8.4	-6.9	2182	798	2124
São Tomé and Príncipe	AFR	7	3.5	-6.5	-10.0	16	21	55
Timor-Leste	EAP	37	5.0	-6.8	-11.8	105	217	578
Tunisia	MNA	204	2.4	-7.0	-9.5	458	634	1688
Ukraine	ECA	426	3.0	-7.2	-10.2	1032	19	50
Uzbekistan	ECA	703	6.0	0.7	-5.3	884	778	2070
Vanuatu	EAP	9	3.1	-8.3	-11.4	23	172	458
Vietnam	EAP	1610	6.5	1.6	-4.9	1872	16	41
Zambia	AFR	622	1.7	-4.8	-6.5	963	529	1407
Zimbabwe	AFR	442	2.7	-10.4	-13.1	1375	271	721
Panel C: Upper-Middle Income Economies [a]								
Albania	ECA	34	4.0	-7.5	-11.6	63	11	116
Algeria	MNA	1032	2.4	-5.5	-7.9	1305	223	2388
Argentina	LAC	755	-1.3	-11.8	-10.5	1276	218	2333
Armenia	ECA	42	4.8	-4.5	-9.3	62	11	114
Azerbaijan	ECA	169	2.1	-4.0	-6.1	167	28	305
Belarus	ECA	112	0.3	-3.0	-3.3	59	10	108

Belize	LAC	8	2.1	-16.0	-18.1	23	4	42
Bosnia and Herzegovina	ECA	27	2.6	-6.5	-9.1	40	7	74
Botswana	AFR	56	4.3	-9.6	-14.0	126	22	231
Brazil	LAC	2934	2.0	-5.8	-7.8	3700	632	6768
Bulgaria	ECA	63	3.2	-4.0	-7.2	73	13	134
China	EAP	16978	5.8	1.9	-4.0	10835	1852	19818
Colombia	LAC	739	3.6	-8.2	-11.8	1407	240	2573
Costa Rica	LAC	70	2.5	-5.5	-8.0	91	15	166
Dominican Republic	LAC	208	5.2	-6.0	-11.2	375	64	686
Ecuador	LAC	336	0.5	-11.0	-11.5	621	106	1135
Equatorial Guinea	AFR	43	-5.0	-6.0	-1.0	7	1	13
Fiji	EAP	19	3.0	-21.0	-24.0	73	13	134
Gabon	AFR	67	3.4	-2.7	-6.1	65	11	120
Georgia	ECA	54	4.8	-5.0	-9.8	86	15	157
Grenada	LAC	2	2.7	-11.8	-14.5	4	1	8
Guatemala	LAC	423	3.5	-2.0	-5.5	377	64	690
Guyana	LAC	16	85.6	26.2	-59.4	149	25	273
Iran	MNA	1552	0.0	-5.0	-5.0	1257	215	2298
Iraq	MNA	1104	4.7	-12.1	-16.7	2972	508	5436
Jamaica	LAC	47	1.0	-8.6	-9.6	73	13	134
Jordan	MNA	215	2.4	-5.0	-7.4	255	44	467
Kazakhstan	ECA	389	3.9	-2.7	-6.6	413	71	756
Lebanon	MNA	117	0.9	-25.0	-25.9	488	83	893
Libya	MNA	126	0.0	-66.7	-66.6	1353	231	2475
Malaysia	EAP	527	4.4	-6.0	-10.4	882	151	1613
Maldives	SAR	7	6.0	-18.6	-24.6	28	5	52
Mauritius	AFR	13	3.8	-14.2	-18.0	38	6	69
Mexico	LAC	2224	1.3	-9.0	-10.3	3670	627	6713
Montenegro	ECA	7	2.5	-12.0	-14.5	17	3	32
Namibia	AFR	70	1.6	-5.9	-7.4	83	14	153
North Macedonia	ECA	23	3.4	-5.4	-8.8	32	5	58
Paraguay	LAC	143	4.0	-4.0	-8.0	185	32	338
Peru	LAC	574	3.6	-13.9	-17.6	1621	277	2966
Romania	ECA	192	3.5	-4.8	-8.3	256	44	468
Russia	ECA	1858	1.9	-4.1	-6.0	1788	306	3271

Samoa	EAP	5	4.4	-5.0	-9.4	7	1	13
Serbia	ECA	84	4.0	-2.5	-6.5	87	15	160
South Africa	AFR	1185	1.1	-8.0	-9.1	1730	296	3165
Sri Lanka	SAR	339	3.5	-4.6	-8.1	441	75	806
St. Lucia	LAC	2	3.2	-16.9	-20.1	7	1	13
St. Vincent and the Grenadines	LAC	2	2.3	-7.0	-9.3	2	0	4
Suriname	LAC	11	2.5	-13.1	-15.6	27	5	49
Thailand	EAP	725	3.0	-7.1	-10.2	1183	202	2164
Tonga	EAP	3	3.7	-2.5	-6.2	3	0	5
Turkey	ECA	1318	3.0	-5.0	-8.0	1689	289	3089
Turkmenistan	ECA	139	6.0	1.8	-4.3	95	16	174
Venezuela, RB	LAC	528	-10.0	-25.0	-15.0	1273	218	2328

[a] The country classification into income and region groups follows the World Bank classification for fiscal year 2021. AFR = sub-Saharan Africa; EAP = East Asia and Pacific; ECA = European and Central Asia; LAC = Latin America and Caribbean; MNA = Middle East and North Africa SAR = South Asia;

[b] Number of births projected by the United Nations World Population Prospects 2019.

[c] Projections by the IMF World Economic Outlook for 2020.