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Abstract

In times of epidemics and pandemics, depletion or diversion of health system resources from routine health care is common, posing serious threats to primary care. This paper estimates the contemporaneous and long-run effects of health disasters on maternal and child mortality in 111 countries during 2000-2019 using two-way fixed-effects and two-step system general method of moments frameworks. We also provide evidence that indicates how health system, macroeconomic, institutional, and structural characteristics can mitigate disaster effects. In low- and middle-income countries, health disasters increase maternal, under-5, and neonatal mortalities by 0.3%, 0.3%, and 0.2% instantaneously and by 35%, 80%, and 26% after one year, respectively. Our estimates show that disaster preparedness can prevent these effects. However, other mitigators, namely health emergency finance, universal health coverage, education, gender equality, and water, sanitation, and hygiene coverage, have greater impact.

Keywords: Preparedness; mitigation; health emergency; epidemic; maternal mortality; child mortality.

JEL Classifications: I1; I18; H5; H51.

1. Introduction and background

During disease outbreaks, surging demand for health care to care for the affected, deaths and illness among health providers, destruction of health facilities, and disruption of electricity, water, and sanitation, and supply chains inevitably jeopardize the provision of routine health services (Kruk et al., 2016). Such testing of the resilience of a nation's health system disproportionately affects pregnant women and children during and in the aftermath of disasters (Harville et al., 2010).

The COVID-19 pandemic began at a time when low- and middle-income countries (LMICs) had achieved improved maternal and child health, with a 38% drop in maternal mortality and a halved child mortality from 2000 to 2018 (World Health Organization, 2020). Yet, with less than a decade left to achieve the United Nations' Sustainable Development Goals (SDGs), progress toward SDG3 "Ensure healthy lives and promote well-being for all at all ages" has been uneven. Strengthening preparedness for health emergencies becomes more urgent as health disasters continue to erode recent gains. The United Nations Independent Accountability Panel (2020) released concerning figures about the impact of the pandemic in January-April 2020. First, women, children, and adolescents lost access to 20% of health and social services as a result of the COVID-19 pandemic. Second, about 13.5 million children missed life-saving vaccinations over the first four months of 2020; such skipping is particularly dangerous in LMICs. Third, before the pandemic, approximately 295,000 women died during or shortly after pregnancy in 2017. These and other statistics show that addressing avoidable maternal and child mortality is paramount in disaster mitigation.

Empirical research on maternal and child health during disease outbreaks is still in its infancy, with very few quantitative studies examining the various facets of disease outbreak impacts. Conceptually and statistically, research has examined the effect of disease outbreaks on maternal and child mortality in single LMICs. However, the scale of nationwide averages ignores more micro-level impacts at the local level and the effects of outbreaks on neighboring countries. Evidence from the 2014 Ebola outbreak in Guinea, Liberia, and Sierra Leone reveals a deterioration in the uptake and provision of maternal and child health services (Delamou et al., 2017; Iyengar et al., 2015; Sochas et al., 2017). Studies reported significant reductions in facility-based deliveries and utilization across the three countries, compared to pre-outbreak metrics. Estimating the indirect effect of COVID-19 on maternal and child mortality in LMICs, Roberton et al. (2020) modeled three possible scenarios of reduction in the coverage of essential maternal and child health services over 3, 6, and 12 months, using the Lives Saved Tool (LiST). They estimated, for example, that 1,157,000 additional child deaths and 56,700 additional maternal deaths occurred across the 118 countries included in the analysis due to reductions of around 45% for 6 months were estimated to result in. Using a similar LiST model, Menendez et al. (2020) estimated the indirect impact of the COVID-19 pandemic on maternal and newborn health in India, Indonesia, Nigeria, and Pakistan over 12 months. Their results suggest that the pandemic will yield an estimated 766,180 additional maternal and newborn deaths and stillbirths, which corresponds to a 31% increase in mortality.

Most recent empirical literature on the indirect effects of health disasters and disaster mitigation measures focuses on clinical factors associated with maternal and child mortality in individual countries and uses facility-level data. However, an array of social and economic *macro-structural* determinants, ranging from social structures to the functioning and responsiveness of health systems, affects maternal and child health. A careful understanding of these determinants and how they operate during public health emergencies is central to sustain achieved health gains, reach the women and children still excluded from recent improvements, and mitigate the negative effects of health disasters.

This paper addresses the gap in the literature by estimating both the short- and long-run effects of epidemic and pandemic disasters on maternal and child health across different groups of countries and by providing evidence of how governments can mitigate the negative effects. Specifically, we seek to answer three questions: (1) What is the indirect short- and long-run impact of disease outbreaks on maternal, under-5, and neonatal mortality? (2) What role does health emergency preparedness (including surveillance, response, preparedness, and risk communication) play in mitigating the effects of outbreaks? (3) Which of these factors mitigate health disaster effect: health service coverage; health emergency finance; water, sanitation, and hygiene (WASH) coverage; education; and gender equality? To answer these questions, we estimate two-way fixed-effects and two-step "system" generalized methods of moments (GMM) models based on the available data for 111 countries, of which we consider 93 to be LMICs, between 2000 and 2019.

The novelty of this study is twofold. First, to our knowledge, this is the first empirical study to provide *macroeconomic* evidence on the indirect impact of disease outbreaks on maternal and child mortality and to quantify this impact in both the short and long runs. Similar studies use facility-level data, which, while being well positioned to capture one-time drops in health service utilization, is not appropriate to capture the effect of system preparedness. Importantly, we estimate this impact within a holistic framework that accommodates the well-established determinants of maternal and child mortality in the spirit of McCarthy and Maine (1992) and Mosley and Chen (1984), respectively. Second, this study is the first to weigh the significance of health emergency preparedness in mitigating the negative effects of disease outbreaks against other mitigation factors. Our findings provide timely insights on how we can efficiently mitigate the effects of health disasters to prevent maternal and child deaths as well as how to improve preparedness for future disasters.

2. Data and conceptualization

To answer our research questions, we construct a panel dataset by merging maternal and child health indicators (dependent variables) with the occurrence of and estimated people affected by epidemic and pandemic disasters (main explanatory variable); established determinants of maternal and child health; and potential mitigators of health disasters (explanatory variables). The analysis is conducted at the country level across all world regions over the period 2000-2019 to address the need for global evidence. A total of 111 countries are covered, out of which

23 are low-income, 70 are middle-income, and 18 are high-income countries (HICs), allowing us to compare the *(mitigated)* health effects in LMICs and in HICs. A full list of covered countries is provided in Appendix A.

2.1. Health indicators

Three health indicators available in the United Nations Global SDG Indicators Database constitute our dependent variables: maternal mortality ratio (MMR, modeled estimate, per 100,000 live births), neonatal mortality rate (NMR, per 1,000 live births), and under-5 mortality rate (U5MR, per 1,000 live births). MMR is a key impact indicator for women's health and well-being, which reflects the health system's capacity to provide effective health care in preventing and addressing the complications that occur during pregnancy and childbirth. NMR and U5MR are key impact indicators for child health and well-being, which reflect the access of children and communities to basic health interventions (e.g., vaccination, medical treatment of infectious diseases, etc.).[3]

2.2. Health disasters

Our two main explanatory variables are (1) the occurrence of and (2) estimated people affected by epidemic and pandemic disasters. Information on health disasters and their human impacts is extracted from the Emergency Events Database (EM-DAT), which is a service of the Centre for Research on the Epidemiology of Disasters (CRED).[4] The EM-DAT reports the number of people killed or injured or rendered homeless as a result of disease outbreaks. A disaster is defined as an incident meeting any of the following criteria: (1) 10 or more people reported killed; (2) 100 people reported affected; (3) declaration of a state of emergency; or (4) call for international assistance. The EM-DAT categorizes disease outbreaks, including pandemics and epidemics, under the biological subgroup (epidemic, pandemic, insect infection, and animal accident) of natural disasters.

As we presume that the impact of disease outbreaks on maternal and child health depends on the magnitude of disasters, we standardize our disaster measure (2) of the estimated number of people affected by epidemic and pandemic disasters. Since the disaster itself affects the current year's population, we divide the measures of the number of people affected by the population size in the year *prior* to the disaster (Przylnski & Hallegatte, 2010; Noy, 2009; Raddatz, 2007). To verify that the way we construct the disaster measure does not raise any endogeneity concerns, we also estimate our exact model using our disaster measure (1) as a binary dummy indicator of disaster occurrence.

[3] The definitions of and rationale for MMR, NMR, and U5MR are provided online at https://unstats.un.org/wiki/display/SDGeHandbook/Home

[4] Established in 1973 as a non-profit institution, CRED is based at the Catholic University of Louvain in Belgium and publicly available on CRED's website at www.cred.be.

2.3 Determinants of maternal mortality

Selection of the determinants of MMR is based on robust evidence from both country- and individual-level studies in the spirit of the McCarthy-Maine (1992) framework for analyzing the determinants of maternal mortality. Analyzing the cultural, social, economic, behavioral, and biological factors influencing maternal mortality, they concluded that all determinants of maternal mortality are associated with pregnancy and pregnancy-related complications. These two outcomes are directly influenced by five sets of woman-related *intermediate* determinants: health status, reproductive status, access to health services, health care behavior, and other unknown or unpredicted factors. In turn, three sets of socioeconomic and cultural factors (*distant* determinants) influence the intermediate determinants: women's status in family and community, family's status in community, and community's wealth. We include MMR country-level determinants previously explored in the literature and variables identified as MMR determinants at the individual or household level and that can be extrapolated from the micro-level to the macro-scale to suit our country level analysis.[5]

We include a set of variables to reflect four general categories of MMR determinants. The first pertains to *economic status* (Anand & Bärnighausen, 2004; Ensor et al., 2010), and is captured by one variable: gross domestic product (GDP) per capita (constant 2010 US$). This variable is a proxy for community's aggregate wealth or, generally, community's status (McCarthy & Maine, 1992).

The second pertains to *health,* and is captured by five variables: physician density (per 1,000 people), a measure of community's health resources or, generally, community's status (Anand & Bärnighausen, 2004; McCarthy & Maine, 1992); adolescent fertility rate (births per 1,000 women ages 15-19), a measure of reproductive health (Godefay et al., 2015; Makinson, 1985; McCarthy & Maine, 1992); births attended by skilled health staff (%), a measure of the use of modern care for delivery or, generally, utilization of health services and health care behavior (Berhan & Berhan, 2014; McCarthy & Maine, 1992);[6] prevalence of anemia among women of reproductive age (% of women ages 15-49), a measure of nutritional status or, generally, health status (Brabin et al., 2001; Daru et al., 2018; McCarthy & Maine, 1992); and incidence of tuberculosis (per 100,000 people), a measure of prevalence of infectious diseases or, generally, health status (McCarthy & Maine, 1992; Moran & Moodley, 2012; Zaba et al., 2013).

The third category pertains to *education* (Anand & Bärnighausen, 2004), and is captured by one variable: female primary completion rate (% of relevant age group). This is a measure of women's education and, generally, a proxy for women's status in family and community (McCarthy & Maine, 1992).

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[5] One example is mother's education that can be captured at the country level by female educational attainment.

[6] Skilled-assisted delivery is of particular relevance to MMR as it can help stop around 16%-33% of maternal deaths through the primary or secondary prevention of four life-threatening obstetric complications (Graham et al., 2001).

The fourth category pertains to *gender equality* (Chirowa et al., 2013), and is captured by one variable: the gender parity index for gross enrollment ratio in primary education, defined as the ratio of girls to boys enrolled at primary level in public and private schools.[7] This is a proxy measure for women's social autonomy or women's status in family and community in the broad sense (McCarthy & Maine, 1992).

We also control for the type of residence or, at the country scale, the degree of urbanization using one variable urban population (% of total population). The significance of this factor remains controversial in the literature (Matthews et al., 2010).

2.4. Determinants of child mortality

Selection of the determinants of U5MR, including NMR, is based on previous evidence from country- and individual-level studies in the spirit of Mosley and Chen's (1984) analytical framework for the study of child survival. They theorize that the relationship between income (per capita) and child mortality is mediated through underlying socioeconomic status, which manifests in *proximate* determinants influencing the risk of disease that, in turn, links to the probability of death. We draw from both U5MR country- and individual- or household-level determinants explored in the empirical literature.

We include a set of variables to reflect four main channels through which socioeconomic status can influence the risk of childhood disease and thus U5MR, in harmony with the earlier classification of MMR determinants. The first channel pertains to *economic status* (Farahani et al., 2009; O'Hare et al., 2013), and is captured by GDP per capita (constant 2010 US$). In a sense this variable reflects financial access to health care.

The second channel pertains to *health*, and we capture it four variables. The first is physician density (per 1,000 people), a proxy for health system resources in general (Anand & Bärnighausen, 2004; Hanmer et al., 2003; Jamison et al., 2016). The second is DPT immunization (% of children ages 12-23 months),[8] a proxy for vaccination coverage and utilization of health care services in the broad sense (Chowdhury et al., 2020; Hanmer et al., 2003; Jamison et al., 2016)[9] that is irrelevant to NMR. The third is the percentage of the population using at least basic drinking water services (Hanmer et al., 2003; Kayode et al., 2012; Kipp et al., 2016). The fourth is the percentage of the population using at least basic sanitation services (Hanmer et al., 2003; Kayode et al., 2012; Tagoe et al., 2020).

[7] Further details on the gender parity index are provided online at http://mdgs.un.org/unsd/mi/wiki/3-1-Ratios-of-girls-to-boys-in-primary-secondary-and-tertiary-education.ashx

[8] DPT: diphtheria, tetanus toxoids, and pertussis.

[9] Jamison et al. (2016) describe vaccination coverage, which some studies consider a health policy measure, as a potential determinant of technical progress as it provides a natural indicator of the extent to which a country's health services adopt powerful mortality-reducing technologies.

The third channel pertains to *education*, specifically mother's education (Anand & Bärnighausen, 2004; Hanmer et al., 2003; Jamison et al., 2016). It is captured by the percentage of women in the relevant age group who have completed primary education, a proxy for mothers' knowledge of health care practices.

The fourth channel pertains to *gender equality* (Hanmer et al., 2003). It is captured by the gender parity index for gross enrollment ratio in primary education.

Moreover, we include one variable to reflect the type of residence or, at the country scale, the degree of urbanization: urban population (% of total population).[10]

The United Nations Global SDG Indicators Database provides the maternal and child mortality determinants used here.[11]

2.5. Disaster mitigating factors

Women and children suffer from various inequities and discrimination based on, for instance, gender, income, age, place of residence, education, as well as health inequities, resulting in worse health outcomes (Temmerman et al., 2015). Thus, we construct a comprehensive dataset of macro-level mediating factors that measure these inequities and discrimination forms. We group the included factors into five categories: (1) health service coverage, (2) public health emergency management, (3) health emergency finance, (4) WASH coverage, and (5) education and gender equality. We hypothesize that these factors can mitigate (or exacerbate) the negative impact of health disasters on maternal and child mortality.

Health service coverage is proxied by the universal health coverage (UHC) service coverage index and physician density (per 1,000 people). The former is defined as the average coverage of essential services pertaining to reproductive, maternal, newborn and child health; infectious diseases; non-communicable diseases; and service capacity and access.[12] UHC advances maternal and child health in several ways, most importantly through promoting the removal of point-of-care fees for essential services and, therefore, reducing the vulnerabilities of the most marginalized groups during health disasters (Temmerman et al., 2015). In parallel, a high density of physicians can help absorb the increased demand for health care that outbreaks bring.

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[10] Some studies suggest urban-rural residence, or the ecological setting in the broad sense, is a differentiating factor for U5MR (Chowdhury et al., 2020; Hanmer et al., 2003; Jamison et al., 2016; Kayode et al., 2012; Kipp et al., 2016; Van Malderen et al., 2019; Yaya et al., 2018), but other studies present more mixed findings (e.g., Matthews et al., 2010).

[11] We ideally would have included estimates for health expenditure (% of GDP; Kipp et al., 2016), poverty headcount ratios (Anand & Bärnighausen, 2004), modern contraceptive prevalence rates (Aheto, 2019; Hanmer et al., 2003; Haroun et al., 2007; Kayode et al., 2012; Kumar et al., 2000; Tagoe et al., 2020), antenatal care coverage (4+visits) (Kayode et al., 2012), exclusive breastfeeding (% of children under 6 months; Kayode et al., 2012; Mani et al., 2012), and prevalence of underweight (% of children under 5; Hanmer et al., 2003; Haroun et al., 2007; Tagoe et al., 2020; Yaya et al., 2018), but this data is too sparse to be used at the country level.

[12] A detailed description of the UHC service coverage index is provided online at https://www.who.int/data/gho/indicator-metadata-registry/imr-details/4834

Stronger preparedness for public health emergencies is likely to reduce the risks and the impact of all-hazards emergencies on population health (Khan et al., 2018). To reflect the overall health system capacity for *public health emergency management,* we use the International Health Regulations core capacity index, which is the average of attributes of 13 core capacities: national legislation, policy, and financing; coordination and national focal point communications; surveillance; response; preparedness; risk communication; human resources; laboratory; points of entry; zoonotic events; food safety; chemical events; and radio-nuclear emergencies. While all these capacities are necessary for the effective management of health disasters, we separately report the mitigation effects of four highly relevant capacities: surveillance, response, preparedness, and risk communication.[13]

Most maternal and child deaths occur in LMICs whose limited resources have historically hindered their ability to provide adequate quality of care even in the absence of health disasters. *Health emergency finance* can play a pivotal role in channeling resources to impacted countries whose health systems are already financially pressured. In the broad sense, impacted countries and individuals can draw from different financial sources to mitigate the disaster effect; five variables are included to represent these sources: total official development assistance (ODA) to medical research and basic health sectors, personal remittances received (% of GDP), GDP per capita (constant 2010 US$), adjusted net savings (% of gross national income), as well as commercial bank branches (per 100,000). The latter reflects financial inclusion. These sources increase the fiscal space of LMICs and the purchasing power of their populations for more health investments. Financial inclusion is associated with individuals' ability to access timely and appropriate health services during health disaster episodes. Impacted individuals typically suffer from income loss because of their inability to work and their need for medical treatment and to meet the incurred payments.

Access to WASH services is essential to population health in normal times. It becomes even more important during disease outbreaks, as WASH interventions have consistently reduced both the risk of disease and the risk of transmission in a variety of settings. Such initiatives involve, variously, handwashing and hygiene education, greater access to drinking water, and improved toilets.[14] Vulnerable women and children exhibit the greatest benefits from such interventions (Akseer et al., 2020). The three variables we use to capture WASH coverage as a measure of disaster preparedness are also used to measure socioeconomic determinants of child mortality: use of drinking water services and safe sanitation services and access to basic handwashing facilities.

Finally, the analysis includes three measures of *education and gender equality*: female primary completion rate (% of relevant age group); the gender parity index for gross enrollment

[13] A comprehensive description of the data coverage, reporting, aggregation, and anonymization of the International Health Regulations core capacity index is provided online at https://www.who.int/health-topics/international-health-regulations#tab=tab_1

[14] A detailed description of WASH interventions and data is provided online at https://data.unicef.org/resources/wash-water-supply-sanitation-hygiene/

ratio in primary education; and the women, business, and the law index. The latter is consists of eight indicators reflecting women's interactions with the law in the eight areas of mobility, workplace, pay, marriage, parenthood, entrepreneurship, assets, and pension[15] and is a proxy measure for women's social and legal autonomy. Reports indicate education was associated with higher levels of resilience after a natural disaster over the long term (Frankenberg et al., 2013). Several studies have recognized the effect of gender inequality on disease transmission (e.g., Ehrhardt et al. (2009) on gender inequality, women empowerment, and HIV/AIDS).

The United Nations Global SDG Indicators Database provided all of the disaster mitigating factor data except the public health emergency management measures, which we obtained from the World Health Organization.

3. Methodology

3.1. Estimating health disaster impacts

3.1.1. Static longitudinal specification

Drawing from Farahani et al. (2009) from the health economics literature and Noy (2009) from the natural disasters literature, we propose a two-way fixed-effects model to estimate the causal impact of epidemic and pandemic disasters on maternal and child mortality. For each country i at year t, the following *parsimonious* specification is estimated three times, once for each of our health impact indicators of interest:

$$y_{i,t} = \gamma_{0i} + \gamma_1 X_{i,t} + \gamma_2 D_{i,t} + \eta_i + \tau_t + \epsilon_{it} \tag{1}$$

The dependent variable, $y_{i,t}$, is either MMR, U5MR, or NMR for country i at year t. $X_{i,t}$ denotes the four vectors of determinants pertinent to economic status, health, education, and gender equality risk factors for the three health outcomes. $D_{i,t}$ is the epidemic and/or pandemic disaster variable. To investigate whether the way we constructed the damage variable ($D_{i,t}$) could have created any endogeneity problem, we convert the *continuous* disaster measure of the number of people affected into a *binary* indicator for the occurrence of a disaster (1=disaster, 0=no disaster) and examine whether this changes our results[16]. η_i and τ_t are sets of country- and year-fixed effects, respectively. γ_{0i} is a country-specific intercept and ϵ_{it} is a random and normally distributed disturbance term.

By including country fixed effects, we eliminate any confounding from country characteristics, whether observed or unobserved, that are constant over time within each country. We also include period dummies to reflect the global level of health technology available at time t and account for the general improvement in maternal and child health over time. The counterfactual

[15] Further details on the women, business, and the law index are provided online at https://openknowledge.worldbank.org/handle/10986/32639#

[16] Because the binary approach masks the distinctions between the magnitudes of different disasters, we only record (binary variable=1) those disasters whose magnitude is bigger than the mean for that type of disaster data.

of an affected country, then, is the same country without the outbreak effect. If outbreaks increase maternal and/or child mortality, we should observe an increase relative to the country's average levels in the indicator during the outbreak or in the period following the outbreak.

Estimates of the effect of health disasters on maternal and child mortality exploiting cross-sectional variability are likely to be biased upward (in absolute value). Empirically, the magnitude of health disaster effect is larger among poor countries, ceteris paribus. We expect the effect to be less or insignificant in HICs due to the greater amount of resources allocated to prevention and mitigation efforts. Hence, we reestimate equation (1) by income level and disaggregate countries to LMICs and HICs to attenuate this omitted variable bias.

We are also confident that our fixed-effects model additionally over protects against omitted-variable bias. In particular, the effect of health disasters on the countries that have consistently experienced epidemics and/or pandemics over our estimated time period is under-estimated as pandemics and epidemics are largely part of the "fixed effect" of these countries. Since these countries are also likely to be the most severely affected, the fixed-effects model may yield too conservative estimates. This is accentuated by our use of a relatively short period framework. Moreover, some countries may be poor at the start of our data series because of the disasters they have experienced up to then. Ignoring this effect implies that our conservative estimates are more likely *not* to detect an effect of disasters. But in fact our model produces a substantial detrimental effect of disasters, especially as our time series is extended.

3.1.2. Long-term dynamic specification

Our specification in equation (1) assumes that the impact of health disasters on maternal and child mortality is instantaneous. While most empirical studies make this assumption, we hypothesize that the long-run effects of disasters are not to be underestimated. To allow for the possibility of long-run effects of health disasters on maternal and child mortality, we propose a long-term dynamic specification, where the *lagged* disasters ($D_{i,t-1}$) and the *lagged* determinants ($X_{i,t-1}$), as well as current disasters ($D_{i,t}$) and other determinants ($X_{i,t}$), affect the log of MMR, U5MR, and NMR. The lags of the logs of MMR, U5MR, and NMR ($y_{i,t-1}$) are included as explanatory variables to measure the persistence in the three health indicators. Our model specification becomes as follows:

$$y_{i,t} = \gamma_{0i} + \alpha y_{i,t-1} + \gamma_1 X_{i,t} + \beta_1 X_{i,t-1} + \gamma_2 D_{i,t} + \beta_2 D_{i,t-1} + \eta_i + \tau_t + \epsilon_{it} \quad (2)$$

According to this framework, γ_2 captures the immediate short-run impact of a health disaster on MMR, U5MR, and NMR. The long-run impact begins after a one-year lag and is given by

$$\frac{\gamma_2 + \beta_2}{1 - \alpha},$$

where α captures the persistence of the adjustment process, specifically the total adjustment of the mortality rate following a health disaster.

While the lagged dependent variable is endogenous and typically correlates with the lagged error term, requiring the residuals to sum to zero within countries implies that the errors are correlated. Therefore, the obtained fixed-effects estimates of equation (2) will be biased and inconsistent, especially with few time periods (Blundell et al., 2000; Cameron & Trivedi, 2005; Wooldridge, 2002). Hence, we estimate equation (2) by the two-step Arellano-Bond GMM estimator, first outlined by Arellano & Bover (1995) and developed by Blundell and Bond (1998). Our two-step "system" GMM estimator has superior finite sample properties to handle the issues of endogeneity of contemporaneous changes in the independent variables and the endogeneity of the lagged level of MMR, U5MR, or NMR in the dynamic specification. The two-step estimator combines the regression equation in differences and the regression equation in levels into one system, where the lagged values of the explanatory variables are used as instruments. It is properly designed for dynamic panels that may contain fixed effects and, in addition to these fixed effects, idiosyncratic errors that are heteroskedastic and correlated within but not across countries, as Roodman (2009) argued. Taking the residuals from equation (2), we have the following moment conditions:

$$E[(\epsilon_{i,t} - \epsilon_{i,t-1})X_{i,t-k}] = 0, \;\; E[\epsilon_{i,t}(X_{i,t-k} - X_{i,t-k-1})] = 0 \qquad (3)$$

Moreover, our estimator is properly designed for panel data with large number of cross sections and a relatively short time series, which is the case in this study. To establish our moment conditions, we assume that the disaster and time dummies are strictly exogenous and, hence, serve as standard instrumental variables (IVs). The use of such IVs also helps reduce the incidence of bias due to potential mis-measurement in our exogenous disaster variables. We assume the rest of the current and lagged explanatory variables in equation (2) is potentially endogenous; we construct our moment conditions for each of these variables for each lag length from two and higher.

Diagnostic tests. As the GMM method we employ is, in its essence, an IV one, we consider the Hansen test of exogeneity of instrument subsets to verify that our instruments are valid. We also consider the Arellano-Bond autoregressive (AR) test for autocorrelation of the residuals to verify that the differenced residuals do not exhibit significant AR(2) behavior. The former test has low power if the number of moment conditions is large. So, we follow Roodman (2009) and reduce the instrument count by specifying the use of only two lags in constructing the GMM instruments. Limiting the number of lags prevents possible loss of efficiency that an unrestricted set of lags, potentially introducing a huge number of instruments, can cause.

3.2. Estimating disaster mitigation effects

In additional model specifications, we examine if health system, macroeconomic, institutional, and structural characteristics of countries struck by disease outbreaks have any bearing on the magnitude of the health outcomes trajectory that typically follows. Specifically, we explore the effectiveness of several factors in determining countries' ability to mitigate the impacts of such disasters. To do so, we extend equation (1) to include two more coefficients and examine the significance of the coefficient on each mitigating factor (health service coverage, public health emergency management, health emergency finance, WASH coverage, education, and gender equality), denoted by $Z_{i,t}$, of countries struck by outbreaks. The following specification is estimated:

$$y_{i,t} = \gamma_{0i} + \gamma_1 X_{i,t} + \gamma_2 D_{i,t} + \gamma_3 \left(D_{i,t} \,.\, Z_{i,t}\right) + \gamma_4 Z_{i,t} + \eta_i + \tau_t + \epsilon_{it} \quad (4)$$

The coefficient on the interaction term of disease outbreaks and mitigating factor, γ_3, is our coefficient of interest as it measures the effect of each respective factor on the magnitude of the change in maternal and child mortality associated with an outbreak.

We also account for the direct effect of the mitigating factors, γ_4, to verify that the significance of the interaction coefficient is not a result of the direct correlation between these factors and health indicators.

4. Results and discussion

4.1. Estimated short-run impact of health disasters

We first investigate the impacts of disease outbreaks on maternal and child health indicators using our static model specification. Table 1 shows the results from the fixed-effects model estimation in equation (1) based on the two reported measures of disease outbreaks: occurrence of disasters and estimated number of people affected. The impacts of health disasters are estimated on MMR, U5MR, and NMR. Our estimates indicate a strong detrimental effect of health disasters. Columns 1, 3, and 5 indicate a significant positive impact of epidemics and pandemics occurrence on increasing maternal, under-5, and neonatal mortalities by ~11%, 2%, and 1%, respectively. Using the number of people affected measure of health disasters, columns 2, 4, and 6 confirm the same significant positive impact on increasing maternal, under-5, and neonatal mortalities by ~13%, 1%, and 0.1%, respectively.

Compared to the coefficients of the other economic, health, and education determinants in Table 1, the magnitude of the negative impact of disease outbreaks on MMR is the highest and the most significant. However, it is GDP per capita, which reflects the economic status of each country, that has the highest impact on under-5 and neonatal mortalities. Globally, this provides novel evidence that, over the last two decades, disease outbreaks can be considered the main determinant of the surge or the weakened improvement in maternal mortality and one of the effective determinants of child mortality.

Table 1. Estimated *short-run* impact of health disasters on MMR, U5MR, and NMR (2000-2019) Dependent variables: MMR, U5MR, and NMR

	MMR		U5MR		NMR	
	D_{it}= Disaster dummy (1)	D_{it}= Affected people (2)	D_{it}= Disaster dummy (3)	D_{it}= Affected people (4)	D_{it}= Disaster dummy (5)	D_{it}= Affected people (6)
Health disasters						
Disaster dummy	10.743**		1.707**		0.616***	
	(4.534)		(0.826)		(0.165)	
Affected people		13.445***		1.125***		0.137*
		(2.568)		(0.410)		(0.083)
Other determinants						
Economic status						
GDP per capita	13.123	-14.634	-7.106**	-7.586**	-5.766***	-5.780***
	(16.103)	(16.376)	(2.995)	(2.996)	(0.597)	(0.604)
Health						
Physician density	2.847	-0.822	-1.903**	-1.993**	-0.346*	-0.342*
	(5.927)	(5.700)	(0.925)	(0.923)	(0.184)	(0.186)
Adolescent fertility	2.304***	2.559***				
	(0.372)	(0.361)				
Skilled-assisted delivery	-2.884***	-2.231***				
	(0.346)	(0.361)				
Education						
Primary education completion (F)	-1.376***	-1.297***	-1.903**	-1.993**	-0.346*	-0.342*
	(0.290)	(0.279)	(0.925)	(0.923)	(0.184)	(0.186)
Constant	304.699**	450.892***	175.876***	179.649***	77.099***	77.527***
	(128.491)	(125.870)	(23.591)	(23.576)	(4.702)	(4.751)
Country effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.748	0.767	0.683	0.684	0.748	0.743
Number of countries	81	81	111	111	111	111
Number of observations	360	360	794	794	794	794

Each column represents a separate regression. Standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. F: female.

Our further investigation in Table 2 differentiates between the impact of health disasters in LMICs and in HICs. The estimates indicate that the observed global adverse impact of disasters on maternal and child mortality is basically originating from LMICs rather than HICs. In HICs, epidemics and pandemics appear to have no impact on MMR, U5MR, or NMR.

Next, we examine the extended model specifications that incorporate additional determinants of maternal and child mortality that are commonly used in the empirical literature of maternal and child health. These cover a set of health (anemia prevalence among women of reproductive age, tuberculosis prevalence, DPT immunization, access to drinking water services, and access to sanitation services), gender equality (the gender parity index), and ecological (urbanization degree) determinants. We report the estimates from this exercise in Table A.2 (Appendix A). The results align with our initial hypothesis that, in the time of health disasters, epidemics and/or pandemics become the dominant determinants indirectly affecting maternal and child mortality. Gender inequality comes second, and is particularly relevant in the case of MMR and U5MR.

Table 2. Estimated *short-run* impact of health disasters on MMR, U5MR, and NMR in LMICs versus HICs (2000-2019) Dependent variables: MMR, U5MR, and NMR

	MMR		U5MR		NMR	
	LMICs (1)	HICs (2)	LMICs (3)	HICs (4)	LMICs (5)	HICs (6)
Health disasters						
Disaster dummy	14.129**	-2.379	1.600*	0.231	0.588***	0.179
	(6.142)	(1.972)	(0.959)	(0.412)	(0.192)	(0.223)
Other determinants						
Economic status						
GDP per capita	30.843	-15.274***	-1.606	-7.364***	-5.469***	-3.795***
	(26.042)	(4.373)	(3.894)	(0.876)	(0.778)	(0.475)
Health						
Physician density	1.981	0.828	-1.910*	2.701***	-0.362*	1.251***
	(7.384)	(3.945)	(1.019)	(0.737)	(0.204)	(0.399)
Adolescent fertility	2.185***	-1.142***				
	(0.475)	(0.350)				
Skilled-assisted delivery	-2.749***	-0.569				
	(0.434)	(0.594)				
Education						
Primary education completion (F)	-1.378***	-0.056	-0.662***	-0.019	-0.118***	-0.022*
	(0.380)	(0.141)	(0.049)	(0.024)	(0.010)	(0.013)
Constant	187.231	278.026***	135.489***	83.398***	74.000***	44.766***
	(197.314)	(68.843)	(28.435)	(8.238)	(5.683)	(4.461)
Country effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.765	0.656	0.738	0.703	0.785	0.684
Number of countries	69	12	93	18	93	18
Number of observations	259	101	587	207	587	207

Each column represents a separate regression. Standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. F: female.

4.2. Estimated long-run impact of health disasters

Table 3 lists the results of estimating our long-run dynamic specification in equation (2) for LMICs; these are the two-step system GMM estimates. We include lags of both dependent and independent variables, precisely GDP per capita, physician density, and urbanization degree (for MMR), as instruments. Year dummies are included (but not reported) in all specifications to control for period fixed effects. In Table 4, we report the estimated long-run effects of changes in our explanatory variables of interest on MMR, U5MR, and NMR, indicating how each parameter is calculated.

We find a significant effect of lagged maternal, child, and neonatal mortalities on each current respective mortality. The large coefficients on the lags of MMR, U5MR, and NMR (>0.900) suggest that maternal and child mortality is slow to adjust to occurrence of health disasters in LMICs and tends to persist close to its previous levels (Table 3).

Table 3. Estimated *dynamic* impact of health disasters on MMR, U5MR, and NMR in LMICs (2000-2019) Dependent variables: MMR, U5MR, and NMR

	Parameter	GMM estimate		
		MMR (1)	**U5MR** (2)	**NMR** (3)
Lag log mortality	α	0.981***	0.993***	0.934***
		(0.001)	(0.003)	(0.003)
Health disasters				
Disaster dummy	γ_2	0.003***	0.003***	0.002***
		(0.001)	(0.000)	(0.001)
Lag disaster dummy	β_2	0.004***	0.002***	0.015***
		(0.002)	(0.001)	(0.001)
Other determinants				
Economic status				
Log GDP per capita	γ_{11}	-0.265***	-0.247***	-0.217***
		(0.021)	(0.014)	(0.009)
Lag log GDP per capita	β_{11}	0.253***	0.241***	0.186***
		(0.021)	(0.014)	(0.010)
Health				
Physician density	γ_{12}	-0.027***	-0.007***	-0.034***
		(0.002)	(0.001)	(0.001)
Lag physician density	β_{12}	-0.006***	-0.001**	0.002***
		(0.001)	(0.000)	(0.000)
Constant	γ_{0i}	0.139***	0.026	0.422***
		(0.019)	(0.019)	(0.021)
Year effects		Yes	Yes	Yes
Arellano-Bond test for AR(2) in 1st differences	z-statistic	0.07	0.94	0.12
	Pr > z =	0.941	0.346	0.902
Hansen difference test	χ^2	44.68	46.07	39.94
	Pr > χ^2 =	0.320	0.428	0.686
Number of countries		85	88	88
Number of observations		550	577	577

Columns (1), (2), and (3) represent separate regressions. Estimates are two-step system GMM ones. Robust standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 4. Calculated *long-run* impact of health disasters on MMR, U5MR, and NMR in LMICs from a dynamic model specification

Explanatory variable	Parameter calculation	Long-run effect estimate		
		MMR	**U5MR**	**NMR**
Long-run disaster dummy	$(\gamma_2 + \beta_2)/(1-\alpha)$	0.353***	0.803**	0.258***
		(0.116)	(0.320)	(0.020)
Long-run log GDP per capita	$(\gamma_{11} + \beta_{11})/(1-\alpha)$	-0.598***	-0.934***	-0.468***
		(0.147)	(0.203)	(0.019)
Long-run physician density	$(\gamma_{12} + \beta_{12})/(1-\alpha)$	-1.712***	-1.264***	-0.486***
		(0.098)	(0.442)	(0.029)

Robust standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Significant contemporaneous and long-run effects of health disasters are observed for all three of our health indicators. Specifically, we estimate that occurrence of health disasters increases MMR, U5MR, and NMR, respectively, by about 0.3%, 0.3%, and 0.2% immediately in LMICs (Table 3). While these effects are significant, the magnitude of the long-run effects is much larger, and about 35%, 80%, and 26%, respectively, after a year (Table 4). The lagged values of the disaster dummy are highly significant for all three mortality ratios (Table 3), confirming an appropriate long-term dynamic specification (Table 4). As anticipated, both GDP per capita and physician density have significant short and long-run effects on maternal and child mortality in LMICs (Tables 3 and 4).

The speed of convergence to the long-run steady state, given by $(1 - \alpha)$, is around 1.9%, 0.7%, and 6.6% for maternal mortality, under-5 mortality, and neonatal mortality, respectively, over a one-year period. This reflects how health disasters are hindering LMICs' efforts in meeting international adequate levels of maternal and child mortalities.

As the employed GMM method relies on IVs, we test the validity of the used instruments. For this purpose, the Hansen test for over-identified restrictions is reported in Table 3, with the null hypothesis being that the used instruments are valid. As shown in Table 3, we fail to reject the null hypothesis, verifying that our instruments are valid. We also report the Arellano-Bond autoregressive (AR) test for autocorrelation of the residuals in Table 3. Failing to reject the null hypothesis suggests that the differenced residuals do not exhibit significant AR(2) behavior.

4.3. Estimated effects of disaster mitigating factors

The results presented in Table 5 provide evidence on the determinants of the magnitude of previously identified impact of health disasters on maternal and child mortality in LMICs. Specifically, we estimate equation (4) to test if UHC, public health emergency management, health emergency finance, WASH coverage, education, and gender equality in the countries struck by disasters have any bearing on the magnitude of maternal and child mortality surge. The reported coefficient on the interaction of the disaster measure and the mitigation variable in equation (4) defines the effect of a mitigating factor on the magnitude of the mortality impact indicated in Table 1.

Estimating the role of public health emergency preparedness in mitigating disaster effects, we find that the health system capacity to detect, assess, notify, report, and respond to public health emergencies, summarized by the *health system capacity* variable, significantly mitigates health disaster effects, especially on MMR and U5MR. *Preparedness* is the core system capacity with the highest effect. In LMICs, an increase in the preparedness index by 1 unit is associated with 0.3, 0.1, and 0.01 decrements in the impact of a health disaster on maternal, under-5, and neonatal mortality, respectively. *Risk communication* comes second, with an increase in its index by 1 unit being associated with 0.2 and 0.05 decrements in the impact of a health disaster on MMR and U5MR, respectively. These results suggest that health emergency management (surveillance, response, preparedness, risk communication, etc.) policies can partially absorb the negative effects of health disasters on maternal and child mortality in LMICs. Epidemic and pandemic preparedness especially can have substantially high returns through developing public health emergency response plans.

Ordering the mitigating effects of various factors by effectiveness, *GDP per capita* comes first as the main mitigator of disaster effects, surpassing all sources of domestic and international health emergency finance in LMICs (ODA, personal remittances, and national savings). A 1%

increase in a country's GDP per capita can absorb the disaster effect on maternal, under-5, and neonatal mortalities by 26%, 5%, and 0.4%, respectively. Countries with lower GDP per capita typically face greater difficulty in dealing with disasters due to budgetary restrictions; a government that is cash strapped can hardly mobilize resources to respond to disease outbreaks. Two results are worth noting in this regard: financial inclusion significantly mitigates the disaster effect on MMR and U5MR; and channeling resources through remittances significantly mitigates the disaster effect on U5MR. The latter result suggests that reducing remittance transaction costs as well as strengthening the financial infrastructure that supports remittances can be of particular relevance to mitigating a disaster effect on child mortality.

Health system related factors come second after GDP per capita as key mitigators of disaster effects. An intuitive result is the significant mitigating effect of *physician density* on mortality in all settings. In LMICs, an increase in the *UHC* index by 1 unit is associated with a 4.2 and 0.7 decrements in the health disaster effect on maternal and under-5 mortality, respectively. The reported results suggest that creating UHC systems is a priority investment during COVID-19 and beyond. Moving toward UHC can address barriers to health care access and alleviate any undue financial burden, with spillover effects on health system resilience to health disasters.

Education and gender equality come in third place. An increase in the *gender parity index* by 1 unit is associated with 2, 0.5, and 0.02 decrements in the impact of a health disaster on maternal, under-5, and neonatal mortality, respectively. Pointing in the same direction, an increase in the *women, business, and the law index* by 1 unit is associated with 1, 0.2, and 0.02 decrements in the impact of a health disaster on maternal, under-5, and neonatal mortality, respectively. Moreover, an increase in *female primary education completion rate* by 1% is associated with 1% and 0.03% decrements in the impact of a health disaster on maternal, under-5, and neonatal mortality, respectively. These results suggest that improving female education helps make people resilient to shocks and better cope with stresses these shocks bring; this strengthened resilience lessens the direct and indirect impact of disasters on health and wellbeing. We also conclude that gender inequality is an important factor of disaster mitigation efforts. More unequal societies tend to have fewer resources allocated to mitigation as they are unable to resolve the collective action problem of implementing mitigating measures.

Estimating the disaster mitigating effects of *WASH* coverage, we find that increasing access to safe drinking water, safely managed sanitation, and basic handwashing facilities by 1% absorbs the adverse effect of disasters on MMR by almost 1%. Drinking water and sanitation appear to have a significant mitigating effect on U5MR, while handwashing has a greater effect on NMR. These results suggest that the heterogeneity in health infrastructure between countries matters for controlling and mitigating the effect of disease outbreaks. In the aftermath of disasters, especially in LMIC settings, breakdowns in infrastructure, and specifically failures of basic hygiene, sanitation, and/or running water systems, leave populations susceptible to elevated health risks from disease outbreaks.

Comparing the disaster mitigating effects of several factors, we confirm that while public health emergency management plays a significant role, but it is secondary to the rest of the explored factors.

We reestimate equation (4) exploiting our pooled dataset including HICs and report the results using a disaster occurrence dummy and estimated total affected, respectively, in Tables A.3 and A.4 (Appendix A). The estimates verify our main findings that strengthening public health emergency management, raising GDP per capita, increasing physician density, investing in UHC, promoting gender equality, improving female education, and expanding WASH coverage can significantly mitigate the negative impact of health disasters. Such factors can make countries better able to withstand an initial disaster shock and, importantly, prevent further spillovers on maternal and child health. The impacts are stronger for LMICs than HICs.

Table 5. Mediating factors of health disaster effects on MMR, U5MR, and NMR in LMICs (2000-2019) Dependent variables: MMR, U5MR, and NMR

D_{it}= Disaster dummy	MMR		U5MR		NMR	
Health service access/coverage						
D_{it}* UHC	-4.155***	(0.844)	-0.689***	(0.150)	-0.056	(0.034)
UHC	1.980	(2.158)	0.350	(0.382)	0.059	(0.087)
D_{it}	198.927***	(40.951)	32.019***	(7.258)	3.222*	(1.655)
D_{it}* Physician density	-14.217***	(3.517)	-2.944***	(0.628)	-0.086	(0.128)
Physician density	-14.916**	(5.780)	-1.604	(0.999)	-0.353*	(0.204)
D_{it}	-7.375	(7.256)	-2.619**	(1.300)	0.465*	(0.266)
Public health emergency management						
D_{it}* Health system capacity	-0.261*	(0.152)	-0.084***	(0.032)	-0.005	(0.008)
Health system capacity	0.114	(0.134)	0.010	(0.026)	0.003	(0.007)
D_{it}	11.442	(9.621)	4.830**	(1.984)	0.345	(0.507)
D_{it}* Surveillance	-0.269	(0.162)	-0.061*	(0.034)	-0.004	(0.008)
Surveillance	0.001	(0.101)	0.013	(0.021)	0.004	(0.005)
D_{it}	17.064	(13.145)	4.552	(2.790)	0.396	(0.675)
D_{it}* Response	-0.211	(0.138)	-0.077***	(0.029)	-0.011	(0.007)
Response	0.222**	(0.097)	0.044**	(0.020)	0.011**	(0.005)
D_{it}	12.104	(10.225)	5.339**	(2.146)	0.960*	(0.519)
D_{it}* Preparedness	-0.300***	(0.105)	-0.085***	(0.022)	-0.009*	(0.005)
Preparedness	0.114	(0.072)	0.025*	(0.015)	0.007*	(0.004)
D_{it}	11.604*	(6.425)	4.195***	(1.325)	0.587*	(0.331)
D_{it}* Risk communication	-0.197*	(0.108)	-0.048**	(0.023)	-0.008	(0.006)
Risk communication	-0.025	(0.083)	0.004	(0.018)	0.005	(0.004)
D_{it}	8.290	(7.822)	2.817*	(1.661)	0.629	(0.403)
Health emergency finance						
D_{it}* ODA-health sector	-2.833	(2.962)	-0.057	(0.526)	0.140	(0.107)
ODA-health sector	-6.923**	(2.795)	-1.903***	(0.493)	0.010	(0.100)
D_{it}	21.769**	(10.687)	1.791	(1.904)	0.149	(0.386)
D_{it}* Remittances	-1.249	(0.912)	-0.360**	(0.167)	-0.025	(0.033)
Remittances	0.468	(0.739)	-0.020	(0.135)	-0.066**	(0.027)
D_{it}	15.247**	(6.619)	2.907**	(1.207)	0.782***	(0.242)
D_{it}* GDP per capita	-25.651***	(5.103)	-4.540***	(0.916)	-0.442**	(0.187)
GDP per capita	-40.870*	(21.988)	-0.831	(3.803)	-5.394***	(0.775)
D_{it}	198.233***	(37.239)	34.369***	(6.681)	3.782***	(1.361)
D_{it}* Adjusted net savings	0.117	(0.306)	-0.023	(0.066)	0.029**	(0.014)
Adjusted net savings	0.209	(0.355)	0.026	(0.075)	-0.037**	(0.016)
D_{it}	9.956**	(4.933)	0.736	(1.061)	0.489**	(0.220)
D_{it}* Financial inclusion	-1.450*	(0.746)	-0.393***	(0.130)	-0.002	(0.005)
Financial inclusion	2.513**	(1.097)	0.555***	(0.185)	-0.039**	(0.016)
D_{it}	17.195**	(6.665)	4.469***	(1.158)	0.107	(0.113)
WASH coverage						
D_{it}* Access to drinking water	-1.023***	(0.253)	-0.210***	(0.045)	-0.024	(0.028)
Access to drinking water	-3.038***	(0.695)	-0.608***	(0.124)	-0.006	(0.040)
D_{it}	86.067***	(18.339)	16.510***	(3.285)	0.409	(0.253)
D_{it}* Access to safely managed sanitation	-1.207***	(0.412)	-0.401***	(0.116)	-0.005	(0.009)
Access to safely managed sanitation	-1.146	(0.713)	0.341*	(0.200)	-0.120***	(0.025)
D_{it}	43.368***	(14.114)	12.191***	(3.960)	1.005	(0.665)
D_{it}* Access to handwashing facilities	-0.549*	(0.279)	-0.069	(0.043)	-0.058***	(0.018)
Access to handwashing facilities	0.218	(0.595)	0.180**	(0.091)	0.030	(0.031)
D_{it}	33.796***	(10.610)	5.098***	(1.621)	1.641***	(0.623)
Education and gender equality						
D_{it}* Primary education completion (F)	-1.146***	(0.203)	-0.252***	(0.036)	-0.006	(0.007)
Primary education completion (F)	-3.046***	(0.288)	-0.535***	(0.050)	-0.001	(0.015)
D_{it}	99.085***	(16.150)	20.511***	(2.841)	0.712**	(0.273)
D_{it}* Gender parity index (education)	-1.886***	(0.605)	-0.546***	(0.107)	-0.017**	(0.007)
Gender parity index (education)	-3.722***	(0.785)	-0.588***	(0.136)	-0.109***	(0.010)
D_{it}	186.593***	(57.237)	52.260***	(10.082)	1.864***	(0.594)
D_{it}* Women, business, & the law index	-1.164***	(0.414)	-0.158**	(0.075)	0.023	(0.021)
Women, business, & the law index	-0.378	(0.499)	-0.048	(0.089)	-0.235***	(0.027)
D_{it}	90.762***	(27.827)	12.167**	(5.041)	-1.811	(1.983)

Each row represents a separate regression. Standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. GDP per capita, physician density, primary education completion (F), and country and year effects are included in all estimations. F: female.

5. Conclusion

This study provides novel, global evidence on the short- and long-run impacts of epidemic and pandemic disease outbreaks on maternal and child mortality across 111 countries over the period 2000-2019 in HICs and LMICs. The evidence provides crucial knowledge that should guide future interventions.

Our fixed-effects results show that health disasters have a significant impact on maternal, under-5, and neonatal mortality worldwide, that the impact is significant in LMICs, and that maternal mortality is the most impacted. We hypothesize that this health disaster effect takes place through repeated depletion or diversion of resources providing routine primary care, which distort the overall efficiency of the health system and pose serious threats to health service utilization. Such depletion and diversion occurred during the Ebola outbreak in West Africa (2014-2016); the current COVID-19 pandemic is likely to lead to similar effects (2019-present). Our GMM results show that, in LMICs, health disasters increase maternal, under-5, and neonatal mortalities by 0.3%, 0.3%, and 0.2% instantaneously and by 35%, 80%, and 26% after one year, respectively.

Exploring various mitigating factors of disaster effect, our findings provide pertinent evidence on how LMICs can strengthen their resilience to disease outbreaks by investing in the most effective disaster mitigation strategies. We confirm that public health emergency management, especially preparedness and risk communication, can play a significant role in preventing negative spillover effects from health disasters to maternal and child health. However, its role is secondary to the rest of the factors, namely health emergency finance, UHC, education and gender equality, and WASH coverage. The obtained evidence is stronger for LMICs.

Our findings of the instrumental role of epidemic and pandemic preparedness have direct policy implications. They are consistent with the view that much health spending in LMICs is poorly targeted or otherwise ineffective. Hence, we construct evidence-based policy toolkits for maternal and child health. To effectively absorb disaster effects on maternal mortality, LMICs governments should invest more to ensure UHC, promote equal education opportunities, increase women's access to quality and affordable financial services, close financing gaps to achieve universal access to safely managed sanitation, drinking water, and handwashing facilities, and improve women's economic opportunities and empowerment. As for child health, the discussed policy toolkit should be augmented by personnel remittances as an effective mitigating factor, suggesting that reducing remittance transaction costs as well as strengthening the financial infrastructure that supports remittances is key to mitigating disaster effects on child mortality. In conclusion, our findings suggest that governments, donors, and development partners should target broad development goals within their public health emergency response plans.

References

Akseer, N., Kandru, G., Keats, E. C., & Bhutta, Z. A. (2020). COVID-19 pandemic and mitigation strategies: Implications for maternal and child health and nutrition. *The American Journal of Clinical Nutrition.* https://doi.org/10.1093/ajcn/nqaa171

Anand, S., & Bärnighausen, T. (2004). Human resources and health outcomes: Cross-country econometric study. *The Lancet*, *364*(9445), 1603–1609. https://doi.org/10.1016/s0140-6736(04)17313-3

Arellano, M., & Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. *Journal of Econometrics*, *68*(1), 29–51. https://doi.org/10.1016/0304-4076(94)01642-d

Berhan, Y., & Berhan, A. (2014). Skilled health personnel attended delivery as a proxy indicator for maternal and perinatal mortality: A systematic review. *Ethiopian Journal of Health Sciences*, *24*(0), 69. https://doi.org/10.4314/ejhs.v24i0.7s

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics*, *87*(1), 115–143. https://doi.org/10.1016/s0304-4076(98)00009-8

Blundell, R., Bond, S., & Windmeijer, F. (Eds.). (2000). *Estimation in dynamic panel data models: Improving on the performance of the standard GMM estimator.* Amsterdam New York and Tokyo: Elsevier Science, JAI.

Brabin, B. J., Hakimi, M., & Pelletier, D. (2001). An analysis of anemia and pregnancy-related maternal mortality. *The Journal of Nutrition*, *131*(2), 604S-615S. https://doi.org/10.1093/jn/131.2.604s

Cameron, A. C., & Trivedi, P. K. (2005). *Microeconometrics: Methods and applications.* Cambridge: Cambridge University Press.

Chirowa, F., Atwood, S., & Van der Putten, M. (2013). Gender inequality, health expenditure and maternal mortality in sub-Saharan Africa: A secondary data analysis. *African Journal of Primary Health Care & Family Medicine*, *5*(1). https://doi.org/10.4102/phcfm.v5i1.471

Chowdhury, A. H., Hanifi, S. M. A., & Bhuiya, A. (2020). Social determinants of under-five mortality in urban Bangladesh. *Journal of Population Research*, *37*(2), 161–179. https://doi.org/10.1007/s12546-019-09240-x

Daru, J., Zamora, J., Fernández-Félix, B. M., Vogel, J., Oladapo, O. T., Morisaki, N., … Khan, K. S. (2018). Risk of maternal mortality in women with severe anaemia during pregnancy and post partum: A multilevel analysis. *The Lancet Global Health*, *6*(5), e548–e554. https://doi.org/10.1016/S2214-109X(18)30078-0

Delamou A., El Ayadi AM., Sidibe S., Delvaux T., Camara BS., Sandouno SD., 2017. Effect of Ebola virus disease on maternal and child health services in Guinea: A retrospective observational cohort study. *Lancet Glob Health.* 5:e448-57.

Ehrhardt, A. A., Sawires, S., McGovern, T., Peacock, D., & Weston, M. (2009). Gender, empowerment, and health: What is it? How does it work? *JAIDS Journal of Acquired Immune Deficiency Syndromes*, *51*(supplement 3), S96–S105. https://doi.org/10.1097/qai.0b013e3181aafd54

Ensor, T., Cooper, S., Davidson, L., Fitzmaurice, A., & Graham, W. J. (2010). The impact of economic recession on maternal and infant mortality: Lessons from history. *BMC Public Health*, *10*(1). https://doi.org/10.1186/1471-2458-10-727

Farahani, M., Subramanian, S. V., & Canning, D. (2009). The effect of changes in health sector resources on infant mortality in the short-run and the long-run: A longitudinal econometric analysis. *Social Science & Medicine*, *68*(11), 1918–1925. https://doi.org/10.1016/j.socscimed.2009.03.023

Frankenberg, E., Sikoki, B., Sumantri, C., Suriastini, W., & Thomas, D. (2013). Education, vulnerability, and resilience after a natural disaster. *Ecology and Society*, *18*(2). https://doi.org/10.5751/es-05377-180216

Godefay, H., Byass, P., Graham, W. J., Kinsman, J., & Mulugeta, A. (2015). Risk factors for maternal mortality in rural Tigray, Northern Ethiopia: A case-control study. *PLOS ONE*, *10*(12), e0144975. https://doi.org/10.1371/journal.pone.0144975

Hanmer, L., Lensink, R., & White, H. (2003). Infant and child mortality in developing countries: Analysing the data for robust determinants. *Journal of Development Studies*, *40*(1), 101–118. https://doi.org/10.1080/00220380412331293687

Harville, E., Xiong, X., & Buekens, P. (2010). Disasters and perinatal health: A systematic review. *Obstetrical & Gynecological Survey,* *65*(11), 713–728. https://doi.org/10.1097/ogx.0b013e31820eddbe

Henry, M. W., & Chen, L. C. (1984). An analytical framework for the study of child survival in developing countries. *Population and Development Review*, *10*, 25–45. https://doi.org/10.2307/2807954

Independent Accountability Panel for Every Women Every Child Every Adolescent (IAP). Caught in the COVID-19 storm: Women's, children's, and adolescents' health in the context of UHC and the SDGs. Geneva: IAP, 2020. https://iapewec.org/reports/annual-reports/iap-2020-report.

Iyengar, P., Kerber, K., Howe, C. J., & Dahn, B. (2015). Services for mothers and newborns during the Ebola outbreak in Liberia: The need for improvement in emergencies. *PLoS Currents.* https://doi.org/10.1371/currents.outbreaks.4ba318308719ac86fbef91f8e56cb66f

Jamison, D. T., Murphy, S. M., & Sandbu, M. E. (2016). Why has under-5 mortality decreased at such different rates in different countries? *Journal of Health Economics*, *48*, 16–25. https://doi.org/10.1016/j.jhealeco.2016.03.002

Khan, Y., O'Sullivan, T., Brown, A., Tracey, S., Gibson, J., Généreux, M., … Schwartz, B. (2018). Public health emergency preparedness: A framework to promote resilience. *BMC Public Health*, *18*(1). https://doi.org/10.1186/s12889-018-6250-7

Kruk, M. E., Kujawski, S., Moyer, C. A., Adanu, R. M., Afsana, K., Cohen, J., …Yamey, G. (2016). Next generation maternal health: External shocks and health-system innovations. *The Lancet, 388*(10057), 2296–2306. https://doi.org/10.1016/s0140-6736(16)31395-2.

Makinson, C. (1985). The health consequences of teenage fertility. *Family Planning Perspectives*, *17*(3), 132. https://doi.org/10.2307/2135024

Matthews, Z., Channon, A., Neal, S., Osrin, D., Madise, N., & Stones, W. (2010). Examining the "urban advantage" in maternal health care in developing countries. *PLoS Medicine*, *7*(9), e1000327. https://doi.org/10.1371/journal.pmed.1000327

McCarthy, J., & Maine, D. (1992). A framework for analyzing the determinants of maternal mortality. *Studies in Family Planning*, *23*(1), 23. https://doi.org/10.2307/1966825

Menendez, C., Gonzalez, R., Donnay, F., & Leke, R. G. F. (2020). Avoiding indirect effects of COVID-19 on maternal and child health. *The Lancet Global Health, 8*(7), e863–e864. https://doi.org/10.1016/s2214-109x(20)30239-4

Moran, N. F., & Moodley, J. (2012). The effect of HIV infection on maternal health and mortality. *International Journal of Gynecology & Obstetrics*, *119*, S26–S29. https://doi.org/10.1016/j.ijgo.2012.03.011

Noy, I. (2009). The macroeconomic consequences of disasters. *Journal of Development Economics, 88*(2), 221–231. https://doi.org/10.1016/j.jdeveco.2008.02.005

O'Hare, B., Makuta, I., Chiwaula, L., & Bar-Zeev, N. (2013). Income and child mortality in developing countries: A systematic review and meta-analysis. *Journal of the Royal Society of Medicine, 106*(10), 408–414. https://doi.org/10.1177/0141076813489680

Przyluski, V., & Hallegatte, S. (2010). Climate change adaptation, development, and international financial support: Lessons from EU pre-accession and solidarity funds. *SSRN Electronic Journal.* https://doi.org/10.2139/ssrn.1710476

Raddatz, C. (2007). Are external shocks responsible for the instability of output in low-income countries? *Journal of Development Economics*, *84*(1), 155–187. https://doi.org/10.1016/j.jdeveco.2006.11.001

Roberton, T., Carter, E. D., Chou, V. B., Stegmuller, A. R., Jackson, B. D., Tam, Y., … Walker, N. (2020). 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. *The Lancet Global Health, 8*(7), e901–e908. https://doi.org/10.1016/s2214-109x(20)30229-1

Roodman, D. (2009). How to do Xtabond2: An introduction to difference and system GMM in Stata. *The Stata Journal: Promoting Communications on Statistics and Stata*, *9*(1), 86–136. https://doi.org/10.1177/1536867x0900900106

Sochas, L., Channon, A. A., & Nam, S. (2017). Counting indirect crisis-related deaths in the context of a low-resilience health system: The case of maternal and neonatal health during the Ebola epidemic in Sierra Leone. *Health Policy and Planning, 32*(suppl_3), iii32–iii39. https://doi.org/10.1093/heapol/czx108

Temmerman, M., Khosla, R., Bhutta, Z. A., & Bustreo, F. (2015). Towards a new global strategy for women's, children's and adolescents' health. *BMJ,* h4414. https://doi.org/10.1136/bmj.h4414

Wooldridge, J. M. (2002). *Econometric analysis of cross section and panel data.* Cambridge, MA: MIT Press.

World Health Organization. World Health Statistics 2020. May 2020. https://www.who.int/gho/publications/world_health_statistics/en/.

Zaba, B., Calvert, C., Marston, M., Isingo, R., Nakiyingi-Miiro, J., Lutalo, T., … Ronsmans, C. (2013). Effect of HIV infection on pregnancy-related mortality in sub-Saharan

Africa: Secondary analyses of pooled community-based data from the network for Analysing Longitudinal Population-based HIV/AIDS data on Africa (ALPHA). *The Lancet*, *381*(9879), 1763–1771. https://doi.org/10.1016/s0140-6736(13)60803-x

Appendix A

Table A.1. List of included countries

Low income	Middle income		High income
Afghanistan	Albania	Malaysia	Germany
Burkina Faso	Angola	Maldives	Israel
Burundi	Argentina	Marshall Islands	Italy
Central African Republic	Bangladesh	Mauritania	Korea, Rep.
Chad	Benin	Mexico	Kuwait
Congo, Dem. Rep.	Bolivia	Mongolia	Latvia
Ethiopia	Botswana	Morocco	Mauritius
Gambia, The	Cabo Verde	Myanmar	Palau
Guinea	Cambodia	Namibia	Panama
Guinea-Bissau	Cameroon	Nepal	Romania
Liberia	China	Nicaragua	Saudi Arabia
Madagascar	Colombia	Nigeria	Seychelles
Malawi	Comoros	North Macedonia	Singapore
Mali	Congo, Rep.	Pakistan	Spain
Mozambique	Costa Rica	Papua New Guinea	Sweden
Niger	Cote d'Ivoire	Paraguay	Switzerland
Rwanda	Dominican Republic	Peru	United Kingdom
Sierra Leone	Ecuador	Philippines	United States
Sudan	Egypt, Arab Rep.	Russian Federation	
Tajikistan	El Salvador	Samoa	
Togo	Eswatini	Sao Tome and Principe	
Uganda	Fiji	Senegal	
Yemen, Rep.	Ghana	Solomon Islands	
	Guatemala	South Africa	
	Honduras	Sri Lanka	
	India	Tanzania	
	Indonesia	Thailand	
	Iran, Islamic Rep.	Timor-Leste	
	Iraq	Tonga	
	Jamaica	Turkey	
	Kazakhstan	Vanuatu	
	Kenya	Venezuela, RB	
	Kyrgyz Republic	Vietnam	
	Lao PDR	Zambia	
	Lesotho	Zimbabwe	

Table A.2. Estimated short-run impact of health disasters on MMR, U5MR, and NMR (2000-2019)

Dependent variables: MMR, U5MR, and NMR

	MMR		U5MR		NMR	
	D_{it}= Disaster dummy	D_{it}= Affected people	D_{it}= Disaster dummy	D_{it}= Affected people	D_{it}= Disaster dummy	D_{it}= Affected people
Health disasters						
Disaster dummy	8.777**		1.793**		0.495***	
	(3.997)		(0.730)		(0.146)	
Affected people		6.955***		0.759**		0.060
		(2.451)		(0.353)		(0.071)
Other determinants						
Economic status						
GDP per capita	7.770	-3.155	-1.651	-1.833	-4.070***	-4.032***
	(14.279)	(14.794)	(2.948)	(2.957)	(0.591)	(0.597)
Health						
Physician density	6.737	3.539	-1.270	-1.272	-0.230	-0.208
	(5.509)	(5.528)	(0.829)	(0.831)	(0.166)	(0.167)
Adolescent fertility	1.584***	1.761***				
	(0.366)	(0.373)				
Skilled-assisted delivery	-2.040***	-1.768***				
	(0.307)	(0.327)				
Anemia prevalence (women)	2.711***	1.996**				
	(0.789)	(0.817)				
Incidence of tuberculosis	0.309***	0.296***				
	(0.040)	(0.040)				
Immunization, DPT			-0.353***	-0.351***		
			(0.053)	(0.053)		
Access to drinking water			-0.951***	-0.927***	-0.166***	-0.159***
			(0.106)	(0.106)	(0.021)	(0.021)
Access to sanitation			0.288***	0.261***	-0.044**	-0.051***
			(0.085)	(0.085)	(0.017)	(0.017)
Education						
Primary education completion (F)	-0.850***	-0.848***	-0.422***	-0.423***	-0.060***	-0.060***
	(0.283)	(0.281)	(0.044)	(0.044)	(0.009)	(0.009)
Gender equality						
Gender parity index (education)	-3.103***	-3.151***	-0.735***	-0.737***	-0.215***	-0.219***
	(0.688)	(0.671)	(0.107)	(0.107)	(0.020)	(0.020)
Ecological setting						
Urbanization	1.800**	1.572*	0.255	0.256	0.100***	0.103***
	(0.890)	(0.890)	(0.174)	(0.174)	(0.035)	(0.035)
Constant	343.060**	439.014***	247.197***	249.016***	88.479***	88.647***
	(146.613)	(145.967)	(24.392)	(24.431)	(4.882)	(4.926)
R^2	0.792	0.795	0.771	0.770	0.809	0.806
Number of countries	81	81	110	110	110	110
Number of observations	351	351	764	764	764	764

Each column represents a separate regression. Standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. D_{it} is the EM-DAT health-disaster. Country and year effects are included in all estimations. F: female.

Table A.3. Mediating factors of health disaster effects on MMR, U5MR, and NMR (2000-2019) Dependent variables: MMR, U5MR, and NMR

D_{it}= Disaster dummy	MMR		U5MR		NMR	
Health service access/coverage						
D_{it}* UHC	-3.113***	(0.639)	-0.528***	(0.117)	-0.052**	(0.026)
UHC	0.818	(1.527)	-0.147	(0.280)	-0.080	(0.062)
D_{it}	166.484***	(33.448)	27.286***	(6.138)	3.114**	(1.365)
D_{it}* Physician density	-13.150***	(2.683)	-2.831***	(0.504)	-0.164	(0.103)
Physician density	-14.591***	(4.973)	-1.558*	(0.906)	-0.326*	(0.184)
D_{it}	-2.549	(5.258)	-1.526	(0.992)	0.428**	(0.202)
Public health emergency management						
D_{it}* Health system capacity	-0.311**	(0.135)	-0.096***	(0.030)	-0.009	(0.008)
Health system capacity	0.155	(0.107)	0.024	(0.023)	0.008	(0.006)
D_{it}	16.384*	(8.538)	6.102***	(1.868)	0.752	(0.496)
D_{it}* Surveillance	-0.266*	(0.144)	-0.061*	(0.032)	-0.004	(0.008)
Surveillance	-0.072	(0.079)	-0.006	(0.018)	-0.000	(0.005)
D_{it}	18.913	(11.744)	5.087*	(2.647)	0.585	(0.676)
D_{it}* Response	-0.244**	(0.122)	-0.089***	(0.027)	-0.014**	(0.007)
Response	0.226***	(0.079)	0.050***	(0.017)	0.013***	(0.004)
D_{it}	15.759*	(9.020)	6.582***	(2.001)	1.276**	(0.510)
D_{it}* Preparedness	-0.337***	(0.093)	-0.096***	(0.020)	-0.013**	(0.005)
Preparedness	0.101*	(0.056)	0.023*	(0.012)	0.007**	(0.003)
D_{it}	15.381***	(5.687)	5.249***	(1.245)	0.907***	(0.327)
D_{it}* Risk communication	-0.266***	(0.096)	-0.065***	(0.021)	-0.012**	(0.005)
Risk communication	0.044	(0.066)	0.018	(0.015)	0.007*	(0.004)
D_{it}	15.026**	(6.944)	4.446***	(1.554)	1.014**	(0.395)
Health emergency finance						
D_{it}* ODA-health sector	-1.946	(2.731)	0.029	(0.491)	0.115	(0.099)
ODA-health sector	-5.890**	(2.572)	-1.531***	(0.458)	0.048	(0.093)
D_{it}	18.991*	(9.811)	1.613	(1.768)	0.274	(0.358)
D_{it}* Remittances	-0.925	(0.774)	-0.255*	(0.149)	-0.010	(0.030)
Remittances	0.334	(0.640)	-0.085	(0.123)	-0.075***	(0.025)
D_{it}	12.876**	(5.238)	2.295**	(1.007)	0.701***	(0.202)
D_{it}* GDP per capita	-15.938***	(3.130)	-3.097***	(0.592)	-0.361***	(0.120)
GDP per capita	-36.434**	(16.090)	-5.678*	(2.949)	-5.599***	(0.596)
D_{it}	133.243***	(24.124)	25.171***	(4.555)	3.348***	(0.920)
D_{it}* Adjusted net savings	0.117	(0.255)	-0.025	(0.058)	0.024**	(0.012)
Adjusted net savings	0.294	(0.278)	0.085	(0.062)	-0.019	(0.013)
D_{it}	9.551**	(4.055)	0.885	(0.915)	0.502***	(0.189)
D_{it}* Financial inclusion	-0.425	(0.492)	-0.097	(0.093)	0.025	(0.019)
Financial inclusion	-0.702*	(0.411)	-0.241***	(0.077)	-0.069***	(0.016)
D_{it}	11.803**	(5.571)	2.921***	(1.046)	0.200	(0.219)
WASH coverage						
D_{it}* Access to drinking water	-0.948***	(0.196)	-0.196***	(0.036)	-0.007	(0.007)
Access to drinking water	-3.924***	(0.556)	-0.905***	(0.103)	-0.174***	(0.021)
D_{it}	83.757***	(14.919)	16.363***	(2.771)	1.237**	(0.558)
D_{it}* Access to safely managed sanitation	-0.410***	(0.150)	-0.124***	(0.042)	-0.018**	(0.007)
Access to safely managed sanitation	-1.202**	(0.478)	-0.024	(0.135)	-0.047*	(0.024)
D_{it}	25.891***	(8.342)	6.374***	(2.353)	0.831**	(0.416)
D_{it}* Access to handwashing facilities	-0.549*	(0.279)	-0.069	(0.043)	-0.006	(0.007)
Access to handwashing facilities	0.218	(0.595)	0.180**	(0.091)	-0.001	(0.015)
D_{it}	33.796***	(10.610)	5.098***	(1.621)	0.712**	(0.273)
Education and gender equality						
D_{it}* Primary education completion (F)	-1.168***	(0.167)	-0.257***	(0.031)	-0.021***	(0.006)
Primary education completion (F)	-3.230***	(0.229)	-0.627***	(0.042)	-0.124***	(0.009)
D_{it}	103.695***	(13.712)	21.759***	(2.548)	2.231***	(0.529)
D_{it}* Gender parity index (education)	-1.940***	(0.506)	-0.554***	(0.094)	0.010	(0.019)
Gender parity index (education)	-3.816***	(0.648)	-0.653***	(0.118)	-0.224***	(0.023)
D_{it}	192.777***	(48.259)	53.487***	(8.956)	-0.517	(1.781)
D_{it}* Women, business, & the law index	-1.104***	(0.316)	-0.167***	(0.060)	-0.028**	(0.012)
Women, business, & the law index	-0.045	(0.379)	0.002	(0.071)	0.044***	(0.014)
D_{it}	87.046***	(21.770)	13.019***	(4.147)	2.480***	(0.823)

Each row represents a separate regression. Standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. GDP per capita, physician density, primary education completion (F), and country and year effects are included in all estimations. F: female.

Table A.4. Mediating factors of health disaster effects on MMR, U5MR, and NMR (2000-2019) Dependent variables: MMR, U5MR, and NMR

D_{it}= Affected people	MMR		U5MR		NMR	
Health service access/coverage						
D_{it}* UHC	-1.474	(0.928)	-0.321*	(0.167)	-0.007	(0.036)
UHC	0.808	(1.611)	-0.126	(0.290)	-0.087	(0.063)
D_{it}	44.569**	(21.469)	9.197**	(3.870)	0.332	(0.844)
D_{it}* Physician density	-0.900	(2.251)	-0.150	(0.428)	0.046	(0.086)
Physician density	-16.755**	(5.045)	-2.001**	(0.924)	-0.340*	(0.186)
D_{it}	5.127	(6.224)	0.735	(1.184)	0.255	(0.238)
Public health emergency management						
D_{it}* Health system capacity	1.160*	(0.700)	0.202	(0.161)	0.044	(0.042)
Health system capacity	0.037	(0.100)	-0.008	(0.022)	0.004	(0.006)
D_{it}	-63.690	(43.013)	-10.344	(9.907)	-2.043	(2.572)
D_{it}* Surveillance	1.876	(1.212)	0.354	(0.273)	0.057	(0.070)
Surveillance	-0.149**	(0.072)	-0.024	(0.016)	-0.002	(0.004)
D_{it}	-154.477	(105.033)	-28.409	(23.690)	-4.099	(6.024)
D_{it}* Response	1.113*	(0.654)	0.170	(0.148)	0.013	(0.037)
Response	0.117*	(0.069)	0.013	(0.016)	0.007*	(0.004)
D_{it}	-82.269	(52.234)	-11.544	(11.859)	-0.269	(2.987)
D_{it}* Preparedness	0.514	(0.755)	0.189	(0.169)	0.028	(0.043)
Preparedness	0.005	(0.054)	-0.005	(0.012)	0.003	(0.003)
D_{it}	-16.313	(34.277)	-6.251	(7.657)	-0.457	(1.929)
D_{it}* Risk communication	0.244	(0.498)	0.069	(0.112)	-0.015	(0.028)
Risk communication	-0.061	(0.064)	-0.008	(0.014)	0.004	(0.004)
D_{it}	-9.569	(33.985)	-2.525	(7.617)	1.726	(1.919)
Health emergency finance						
D_{it}* ODA-health sector	-3.187**	(1.508)	-0.404	(0.273)	-0.077	(0.056)
ODA-health sector	-5.580**	(2.504)	-1.430***	(0.447)	0.090	(0.092)
D_{it}	16.668***	(5.218)	2.162**	(0.944)	0.344*	(0.193)
D_{it}* Remittances	0.867	(1.300)	0.160	(0.251)	0.049	(0.051)
Remittances	0.265	(0.641)	-0.101	(0.123)	-0.077***	(0.025)
D_{it}	-1.506	(5.223)	-0.376	(1.008)	-0.122	(0.204)
D_{it}* GDP per capita	-8.762**	(3.443)	-1.416**	(0.655)	-0.013	(0.133)
GDP per capita	-49.925***	(16.293)	-7.998***	(2.994)	-5.784***	(0.605)
D_{it}	60.349***	(20.894)	9.673**	(3.977)	0.214	(0.804)
D_{it}* Adjusted net savings	-0.274***	(0.102)	-0.045*	(0.023)	-0.001	(0.005)
Adjusted net savings	0.134	(0.269)	0.062	(0.060)	-0.022*	(0.013)
D_{it}	4.190*	(2.135)	0.593	(0.488)	0.131	(0.103)
D_{it}* Financial inclusion	0.127	(0.312)	0.032	(0.059)	0.014	(0.012)
Financial inclusion	-0.791*	(0.411)	-0.263***	(0.077)	-0.072***	(0.016)
D_{it}	0.198	(2.497)	-0.016	(0.473)	-0.048	(0.099)
WASH coverage						
D_{it}* Access to drinking water	-0.337*	(0.186)	-0.056	(0.035)	-0.000	(0.007)
Access to drinking water	-4.106***	(0.560)	-0.950***	(0.104)	-0.171***	(0.021)
D_{it}	26.264**	(10.548)	4.253**	(1.968)	0.161	(0.395)
D_{it}* Access to safely managed sanitation	-11.006***	(2.460)	-2.802***	(0.697)	-0.352***	(0.124)
Access to safely managed sanitation	-1.182**	(0.469)	-0.034	(0.133)	-0.050**	(0.024)
D_{it}	470.440***	(105.696)	122.174***	(29.955)	16.295***	(5.332)
D_{it}* Access to handwashing facilities	1.193	(1.981)	-0.273	(0.302)	0.026	(0.051)
Access to handwashing facilities	0.186	(0.615)	0.177*	(0.094)	-0.001	(0.016)
D_{it}	-52.184	(88.247)	12.526	(13.461)	-1.115	(2.262)
Education and gender equality						
D_{it}* Primary education completion (F)	-0.309***	(0.092)	-0.052***	(0.018)	-0.003	(0.004)
Primary education completion (F)	-3.721***	(0.219)	-0.740***	(0.041)	-0.135***	(0.008)
D_{it}	23.502***	(5.250)	3.807***	(0.999)	0.306	(0.202)
D_{it}* Gender parity index (education)	-0.777***	(0.268)	-0.128**	(0.051)	-0.006	(0.010)
Gender parity index (education)	-4.771***	(0.582)	-0.941***	(0.107)	-0.222***	(0.021)
D_{it}	75.214***	(24.037)	12.224***	(4.547)	0.584	(0.892)
D_{it}* Women, business, & the law index	-0.536	(0.476)	-0.065	(0.091)	0.006	(0.018)
Women, business, & the law index	-0.105	(0.377)	-0.008	(0.071)	0.044***	(0.014)
D_{it}	42.966	(31.640)	5.443	(6.020)	-0.271	(1.204)

Each row represents a separate regression. Standard errors are reported in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. GDP per capita, physician density, primary education completion (F), and country and year effects are included in all estimations. F: female.