Health-care worker mortality and the legacy of the Ebola epidemic

The recent outbreak of Ebola in West Africa will leave a legacy significantly deeper than the morbidity and mortality caused directly by the disease. Ebola deaths have been disproportionately concentrated among health personnel. By May, 2015, 0·02% of Guinea's population had died due to Ebola, compared with 1·45% of the country's doctors, nurses, and midwives. In Liberia and Sierra Leone, the differences are more dramatic, with 0·11% and 0·06% of the general population killed by Ebola versus 8·07% of the health-care workers in Liberia, and 6·85% in Sierra Leone.[1–4] The fact that health-care workers are at greater risk of contracting Ebola will exacerbate existing skill shortages in countries that had few health personnel to begin with.

We modelled how the loss of health-care workers—defined here as doctors, nurses, and midwives—to Ebola might affect maternal, infant, and under-5 mortality in Guinea, Liberia, and Sierra Leone, with the aim of characterising the order of magnitude of likely effects, not providing specific predictions. We combined data on: (1) health-care worker deaths from Ebola;[1] (2) the stock of health-care workers pre-Ebola;[5] (3) maternal, infant, and under-5 mortality rates for each country, pre-Ebola;[2] and (4) coefficients of health-care worker mortality, which capture the relation between health-care workers in a given country and different mortality rates (ie, maternal, infant, and under-5 mortality).[3]

For each of the three countries, we first calculated how many doctors, nurses, and midwives combined have died due to Ebola per 1000 of the population. We multiplied each pre-Ebola mortality rate (maternal, infant, and under-5) by 1 minus this fraction, multiplied by the health-care worker mortality coefficient. We then translated this figure into the percentage change in mortality relative to pre-Ebola rates (appendix).

We constructed bounds based on the 95% CIs of the estimated coefficients of health-care worker mortality. These incorporate the estimation uncertainty associated with the health-care worker mortality coefficients and the pre-Ebola mortality rates, under the assumption that the latter uncertainty is constant across countries and over the period between the estimation of the health-care worker mortality coefficients (2006) and the present (2015). However, we were unable to account for the uncertainty surrounding the measurement of health-care worker mortality owing to a lack of data.

As of late May, 2015, Guinea, Liberia, and Sierra Leone, respectively, had lost 78, 83, and 79 doctors, nurses, and midwives to Ebola. The largest effects of these health-care worker deaths for all three countries were on maternal mortality (table), namely increases of 38% (95% CI 26–50) in Guinea, 74% (51–97) in Sierra Leone, and as large as 111% (76–145) in Liberia, relative to pre-Ebola rates. Estimated effects on infant and under-5 mortality ranged from an increase of 7–20% and 10–28% across countries, respectively. However, in both of the latter cases the health-care worker mortality coefficients used were not statistically significant in the original study[3] and the range between the upper and lower bounds of the 95% CIs includes a zero effect (table).

Combining these estimates with the most recent population numbers and rate of livebirths in each country pre-Ebola[2] suggests that an additional 4022 women would die per year in childbirth as a result of doctors, nurses, and midwives lost to Ebola. This would bring the countries back to rates of maternal mortality last seen in 2000 in Guinea and Sierra Leone, and 1995 in Liberia.[2]

These mortality estimates have limitations. The model's use of cross-country mortality coefficients assumes that the effect of health-care worker supply on maternal, infant, and under-5 mortality in Guinea, Liberia, and Sierra Leone is similar to the cross-country average and has not changed since those coefficients were estimated. This work further assumes that unmeasured elements of health systems (such an overall measure of quality), associated with both health-care worker density and mortality, are not driving the result. Data limitations make it difficult to account for these unmeasured factors,

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	Doctors, nurses, and midwives			Maternal mortality ratio (per 100 000 livebirths)			Infant mortality rate (per 1000 livebirths)			Under-5 mortality rate (per 1000 livebirths)		
	Stock pre-Ebola	Stock post-Ebola	% change	Pre-Ebola (2013)	May 2015	% change (95% CI)	Pre-Ebola (2013)	May 2015	% change (95% CI)	Pre-Ebola (2013)	May 2015	% change (95% CI)
Guinea	5395	5317	–1%	650	897	38% (26 to 50)	65	69	7% (–2 to 15)	101	110	10% (–2 to 21)
Liberia	1029	946	–8%	640	1347	111% (76 to 145)	54	64	20% (–4 to 43)	71	91	28% (–5 to 61)
Sierra Leone	1153	1074	–7%	1100	1916	74% (51 to 97)	107	121	13% (–3 to 29)	161	191	19% (–4 to 41)

Data are from author calculations based on Ebola mortality data from WHO,[1] population and maternal mortality data from World Development Indicators,[2] and health worker-mortality coefficients from Speybroeck et al.[3] Data on pre-Ebola stock of health workers is for the most recent years available for each country: 2004 (nurses and midwives) and 2005 (doctors) for Guinea, 2008 for Liberia, and 2010 for Sierra Leone.

Table: **Effects of health-care worker deaths from Ebola on maternal, infant, and child mortality**

but one may consider that health-care workers are a crucial element of all other parts of an effectively functioning health-care system. However, these numbers demonstrate the potentially sizeable legacy that Ebola will leave.

Ebola has weakened already fragile systems, and it should be the catalyst to strengthen the systems far beyond their pre-Ebola levels. Indeed, to reach the minimum 80% health coverage targeted by the Millennium Development Goals, 43 565 doctors, nurses, and midwives would need to be hired across the three countries. Our estimates suggest that substantial investment in health systems—and specifically in the health workforce—is urgently required not only to improve future epidemic preparedness and meet basic needs, but also to limit the secondary health effects of the current epidemic owing to the depletion of the health workforce.

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*David K Evans, Markus Goldstein, Anna Popova
devans2@worldbank.org

World Bank, Washington, DC 20433, USA

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Supplementary appendix

This appendix formed part of the original submission and has been peer reviewed. We post it as supplied by the authors.

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Supplementary appendix

The Relationship between Healthcare Workers and Health Outcomes

A number of studies have attempted to assess the relationship between healthcare workers and health outcomes. Almost all of these rely on regressions of cross-sectional data, but they vary greatly in which outcome variables (different mortality rates, vaccine coverage, or coverage of births by skilled attendants), explanatory variables (density of healthcare workers, doctors, or nurses and midwives), and controls (poverty, GDP, education) they include, as well as in the functional forms used in their econometric analysis (logit-log, log-linear, linear regressions with arcsin and log transformation of the dependent and independent variables, logit-log and arcsine-log model), not to mention in their results. [1] We focus our attention on those studies investigating the effect of healthcare worker density (i.e., the number of healthcare workers per 1,000 of the population) on mortality, as opposed to alternative health outcomes. The relationship between the healthcare workforce and mortality is more studied than other outcomes and serves as a proxy for the overall quality of the health sector.

Early studies found no significant association between doctor density and infant mortality, [2, 3] or even an adverse association (i.e., positive) between the doctor density, and infant and perinatal mortality. [4] However, more recent studies, with access to more extensive and better quality data, have consistently found a negative and a significant association between the density of healthcare workers and mortality.

In this analysis we focus on five of these recent studies. These studies take a range of approaches, which are summarized in Table A1. One key area of difference in the approaches is how they treat health workers: either as an aggregate, or looking at the effects of doctors, nurses, and midwives separately (possibly allowing for an interaction between doctors and nurses). Robinson and Wharrad use data from 155 countries and find a negative relationship between doctor density and maternal, infant, and under-five mortality. However, they find no statistically significant relationship for nurses once they are included with doctors. [5, 6] Anand and Bärninghausen use data from 117 countries and find a significant negative association between the density of aggregate healthcare workers (doctors, nurses, and midwives combined) and maternal, infant, and under-five mortality. They also find a significant negative relationship between doctor density and all mortality rates, while the coefficient for nurses is insignificant once the controls are included. [7] Speybroeck et al. use data for 192 countries. They find a significant negative relationship between aggregate healthcare worker density and maternal mortality, with a similar elasticity to that of Anand and Bärninghausen, but unlike the latter they find the coefficients for infant and under-five mortality to be insignificant. In the case of disaggregate densities – where they are unique in their inclusion of an interaction term between doctor density and the density of nurses and midwives – they again find a significant association between doctor density and all mortality rates, while the relationship for nurses is significant (and negative) only in the case of maternal mortality. [8] Farahani et al. are the first to use panel data in their analysis of 99 countries, which looks at the effect of doctor density on infant mortality. They find that adding one doctor for every 1,000 population is consistent with a significant reduction in infant mortality by about 30%, or 45% in the long-run. [9]

While these recent studies - with their various functional forms - tend to converge on a significant negative association of both aggregate healthcare worker density and doctor density with mortality rates, they also converge in their inability to sufficiently account for other factors that may be driving mortality rates. Notably, there may be a selection problem such that countries with health systems which are weak in ways other than simply having few healthcare workers (e.g., low health expenditure, high geographic concentration of services, limited access to external resources, or inappropriate incentive and decision-making structures) [7, 8] experience high mortality rates precisely due to these other weaknesses. Not only would a wider range of inputs to the production of health ideally be included in the models, but healthcare workers would preferably be separated from the factors likely to mediate the efficiency with which they are able to perform. [8] Data limitations make it difficult to account for these other factors, however, so while these studies acknowledge that the performance of healthcare workers will be dependent on these factors and note their exclusion as a shortcoming, they either argue that healthcare workers are the "glue" that allows the rest of the system to function, [10] or that the workers serve as a proxy for general health system resources. [9]

Methods

As discussed in the letter, we combine data from the following sources to model how the loss of healthcare workers to Ebola will affect non-Ebola mortality in Guinea, Liberia, and Sierra Leone: (1) current healthcare worker deaths from Ebola, disaggregated by country and occupation; (2) the stock of healthcare workers pre-Ebola, similarly disaggregated; (3) maternal, infant, and under-five mortality rates for each country, pre-Ebola; and (4) healthcare worker mortality coefficients, which capture the relationship between healthcare workers in a given country and different mortality rates (i.e., maternal, infant, and under-five mortality).

Addressing the source of each of these in turn, disaggregated data on healthcare worker deaths from Ebola in Guinea, Liberia, and Sierra Leone come from the World Health Organization (WHO), based on the Viral Haemorrhagic Fever database for each country. [11] For doctors, we use the WHO numbers for "medical workers," which include doctors and medical students. We use data on the stock of healthcare workers from the WHO Global Health Workforce Statistics.[i] [12] Pre-Ebola mortality rates for each country come from the World Development Indicators (WDI). [13] These define the maternal mortality ratio as the number of women who die from pregnancy-related causes while pregnant or within 42 days of pregnancy termination per 100,000 live births, and infant and under-five mortality rates as the probability per 1,000 that a newborn baby will die before reaching the ages of one or five, respectively. We use coefficients from Speybroeck et al. [8] as our main estimates for the association between aggregate healthcare worker density (for doctors, nurses, and midwives, combined) and maternal, infant, and under-five mortality as our primary healthcare worker mortality coefficients. The coefficients for under-five mortality used in our chosen specification as well as all robustness tests are calculated using mortality rates for children aged between one and five years as per Speybroeck et al. [8] and Anand and Bärninghausen. [7] We rely principally on the coefficient of Speybroeck et al. because they calculate their healthcare worker mortality coefficients using data with the largest sample of countries, they use the same data source as we use for the stock of healthcare workers, and they provide coefficients for all three types of mortality (maternal, infant, and under-five). Also, in addition to including controls for income poverty, GDP per capita, and female literacy, they run a disaggregated specification, which reports coefficients for doctors and nurses-midwives separately, which we exploit as one of two robustness checks.[ii] Obviously, the difference in definition of under-five mortality between Speybroeck et al. and WDI is a limitation, but the results are still informative as to the likely order of magnitude of effects.

To calculate the effect on mortality due to healthcare worker deaths from Ebola, for each of the three countries, we first calculate how many doctors, nurses, and midwives combined have died due to Ebola per 1,000 of the population to date. We then multiply each pre-Ebola mortality rate (maternal, infant, and under-five) by one minus this fraction multiplied by the healthcare worker mortality coefficient from Speybroeck et al., [8] multiplied by 100, as below.[iii] We then translate this into the percentage change relative to pre-Ebola mortality rates.

$$
\begin{aligned}
&Jan\ 2015\ mortality\ rate \\
&\qquad = pre\ Ebola\ mortality\ rate \\
&\qquad * (1 - (healthcare\ worker\ deaths\ per\ 1{,}000\ population \\
&\qquad * healthcare\ worker\ mortality\ coefficient) * 100)
\end{aligned}
$$

We undertake two measures to assess the robustness of our estimates: (1) we calculate lower and upper bound estimates using the 95% confidence intervals for the healthcare worker mortality coefficients from Speybroeck et al.; [8] and (2) we calculate how much the estimates vary when we use mortality coefficients from the various models discussed in the previous section. For each study providing coefficients for either aggregated healthcare workers, or disaggregated doctors, and nurses-midwives, we choose the coefficients resulting from the authors' preferred specification, for all available mortality rates. Where both aggregated and disaggregated coefficients are reported, we use both to check for robustness, provided that the latter includes nurses and midwives.[iv] Table A1 provides more details on the models underlying each of the coefficients used as robustness checks.

Table A1: Summary of Recent Methods to Calculate Healthcare Worker – Mortality Coefficients

	Farahani et al. [9]	Speybroeck et al. [8]	Anand and Bärninghausen [7]	Robinson and Wharrad [5]	Robinson and Wharrad [6]
Independent variables					
Aggregate healthcare workers	No	Yes	Yes	No	No
Disaggregate doctors & nurses	Doctors only	Yes	Yes	Yes	Yes
Dependent variables					
Maternal mortality	No	Yes	Yes	Yes	No
Infant mortality	Yes	Yes	Yes	No	Yes
Under-five mortality	No	Yes	Yes	No	Yes
Model	Log-level regression with (1) cross-country data, (2) panel data, (3) panel data with country fixed effects and (4) panel data with time lags	Log-linear regression	Log-linear regression	Multiple linear regression with log transformations of doctor density, nurse density and GNP, and arcsin transformations of female literacy and births attended	Multiple linear regression with log transformations of doctor density, nurse density and GNP, and arcsin transformation of female literacy
Controls	GDP per capita, average years of schooling, country fixed effects + lags of all dependent and independent variables for long-term analysis	GDP per capita, income poverty, female literacy	GNI per capita, income poverty, female literacy	GNP, female literacy, births attended	GNP, female literacy
Data	Longitudinal panel data from 99 countries from 1960 to 2000 using data from the WDI, Penn World Table, and the Barro–Lee dataset	WHO database on 192 countries	WHO database on 117 countries or 83 countries when income is included	UN database on 116 countries when female literacy is included	UN database on 116 countries when female literacy is included

Sensitivity Analysis

Table A2 presents estimates for maternal mortality using healthcare worker mortality coefficients from other studies. All three alternative methods also produce large increases in maternal mortality for all countries. The most comparable effects arise from Method 3, which – similarly to Speybroeck et al. – uses an aggregate coefficient for doctors, nurses and midwives, and produces increases in maternal mortality of 31% in Guinea, 61% in Sierra Leone, and 92% in Liberia. The next most similar estimates arise from Method 2, which uses disaggregated coefficients for doctors, and nurses and midwives, plus an interaction term between them. The smallest estimates come from Method 4 which uses disaggregated coefficients but does not account for an interaction effect. This is a serious limitation because doctors and nurses are likely to be complementary: it is not difficult to imagine that a doctor is more likely to be effective at saving lives when there is a nurse present, and vice versa. Nonetheless, even using this method as an absolute lower bound, healthcare worker deaths to date would increase maternal mortality by between 12% and 23% across the three countries.

Table A2: Robustness of Maternal Mortality Estimates to Different Coefficients

	Change in maternal mortality due to healthcare worker deaths from Ebola		
	Guinea	Liberia	Sierra Leone
Method 1: Speybroeck et al. (2006) aggregated doctors and nurses, controlling for GDP per capita, income poverty, female literacy (from Table 1)			
	38%	111%	74%
Method 2: Speybroeck et al. (2006) disaggregated doctors and nurses, plus interaction between doctors & nurses, controlling for GDP per capita, income poverty, female literacy			
	27%	73%	49%
Method 3: Anand and Bärninghausen (2004) aggregated doctors and nurses, controlling for GNI per capita, income poverty, female literacy			
	31%	92%	61%
Method 4: Anand and Bärninghausen (2004) disaggregated doctors and nurses, controlling for GNI per capita, income poverty, female literacy			
	12%	23%	16%

Note: Using coefficients from Robinson and Wharrad [6] yields smaller estimates of 5%, 3%, and 3% increases in maternal mortality for Guinea, Liberia, and Sierra Leone. However, this is explained by the fact that they only report a coefficient for doctors (although nurses are included in their specification, which also controls for GNP, female literacy, and births attended).

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[i] For robustness, we also ran our model with data on the stock of healthcare workers from the World Development Indicators database, [13] which are similar and produced identical effects on mortality.

[ii] This is not our preferred specification because the distribution of doctors versus nurses and midwives may well be endogenous to local factors.

[iii] This is because the coefficients from Speybroeck et al.'s log-linear regressions are elasticities, such that the estimated coefficient b on the log of healthcare worker density can be interpreted as a 1% increase in healthcare worker density, ceteris paribus, leading to a b% change in the mortality rate. [8]

[iv] Robinson and Wharrad and Farahani et al. both report coefficients for doctors only, thus we do not use these as robustness checks as they are not strictly comparable to our model. [5, 6, 9]