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This paper assesses the welfare impacts of the 2014 Ebola Virus Disease (EVD) outbreak in Liberia, focusing on changes in age and sex specific mortality rates. The first part of the paper derives a survival function for a counterfactual no-EVD scenario, using mortality data from the Institute for Health Metrics and Evaluation (IHME). This counterfactual survival function is then compared with the actual survival function in 2014 to estimate the change in survival conditions due to EVD. Next, the impact of this change on individual and total welfare is assessed using a marginal willingness to pay approach applied to data from the Liberian Household Income and Expenditure Survey (HIES). The results suggest that the total welfare costs of EVD-related mortality range between \$2.5 to \$4 billion, depending on the estimate of the survival probabilities adopted. Finally, the robustness of these results is tested using different preference parameter calibrations.

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JEL classification: I31; J17; O55

Keywords: willingness to pay; Ebola; value of life; welfare; cost; Liberia

1 Introduction

In 2014, several countries in West Africa were struck by the largest outbreak of Ebola Virus Disease (EVD) since its initial discovery in 1976. Among the countries affected, Liberia reported the highest number of confirmed EVD-related deaths. By the official end of the outbreak in 2015, there had been 10,666 cases of EVD in Liberia, of which 4,806 were confirmed to be fatal.[1] Still, it is unlikely that this figure captures the true extent of EVD-related mortality in Liberia. First, many cases of EVD were unreported due to the poor coverage of health surveillance systems (Dalziel et al., 2018). Second, the EVD epidemic undermined an already weakened health system, which may have led to a concomitant rise in mortality from other causes of death, such as as HIV/AIDS, malaria, and tuberculosis (Parpia et al., 2016).

While many studies have assessed the economic costs of EVD,[2] few have contemplated the costs of increases in mortality rates for individual and total welfare within the affected countries. Of those that have, the methodologies adopted may fail to capture the true extent of such costs. Kirigia et al. (2015), for instance, adopt a cost of illness approach and value the number of life years lost due to EVD using discounted GDP per capita values. They estimate that the total future productivity losses due to premature deaths from EVD amount to $54 million in Liberia. However, as originally argued by Schelling (1968), there are several ethical reasons not to value a life year lost in terms of foregone output. For instance, this approach does not consider an individual's non-market contributions or own valuation of his or her life. Huber et al. (2018) attempt to capture the latter by multiplying the number of EVD related deaths by an estimate of the value of statistical life (VSL) from a study in Sierra Leone.[3] They estimate the direct costs of EVD-related mortality to be around $6.74 billion across Guinea, Liberia and Sierra Leone. This figure increases to $36.8 billion when the indirect increases in deaths from other diseases are accounted

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[1] Number of cases includes those confirmed, probable and suspected.World Health Organisation Ebola Data and Statistics 4th May 2015. Accessed [10/05/19] at http://apps.who.int/gho/data/view.ebola-sitrep.ebola-summary-latest?lang=en

[2] The World Bank (2016) estimates that the total economic cost of EVD in Liberia to be around $300 million over the period 2014-16, in terms of foregone output, higher prices, lower household incomes and reduced fiscal revenues. The UNDG (2015) reports impacts of a similar order of magnitude, finding that EVD reduced Liberia's GDP by around $188-245 million between 2014 and 2017.

[3] León and Miguel (2017) estimate the VSL for African and non-African travellers by exploiting variation in risky transportation choices from Sierra Leone's airport to its capital Freetown. They note that the VSL estimate is based on the transport choices of relatively rich African travellers in Sierra Leone.

for. Nevertheless, their application of a uniform VSL to every EVD-related death ignores heterogeneities in valuations that may arise due to age, income and other characteristics (e.g. sex), which have been shown to be quantitatively important in the context of welfare measurement (see Cerqueira and Soares, 2016).

The aim of this paper is to quantify the impact of EVD-related mortality on individual and total welfare in Liberia. Unlike the aforementioned papers, this paper takes an ex-ante perspective and estimates individual willingness to pay (WTP) values to avoid the increases in age specific mortality rates associated with the EVD outbreak. This approach dates back to the early works of Usher (1973, 1980) and has been used in several empirical settings that consider the welfare costs of infectious diseases (Philipson and Soares, 2005; Fimpel and Stolpe, 2010). The WTP approach has two advantages over previously employed methodologies. First, it is flexible in the sense that it allows for the estimation of individual WTP values that vary with age and income. For instance, time discounting implies that an individual's WTP to avoid a disease will be greater the closer his current age is to the point of onset.[4] Second, it provides a framework to assess heterogeneities in survival conditions across different demographic groups, in this case between sexes.

The core analysis of this paper draws upon a representative household survey from Liberia, which was carried out just before the outbreak of EVD in 2014. The timing of the survey is important as it allows for an approximation of the mortality-related welfare costs of EVD (i.e. by holding EVD-induced changes in consumption constant). This dataset is complemented with age and sex specific mortality rates to derive individual WTP values to avoid the mortality increase associated with EVD. Following this, the individual WTP values are aggregated to arrive at an estimate of the total cost of the EVD-related mortality in Liberia. The analysis suggests that these costs far outweigh those based on economic impacts alone. More specifically, the total welfare loss due to EVD-related mortality ranges from around $2.5 to 4 billion, depending on the bound of the survival estimates used. These lower and upper bounds amount to approximately 80% and 128% of Liberia's total GDP in 2014, respectively. Moreover, these costs appear to be greater for males than for females. This result seems to be driven by the higher age-specific EVD-related mortality rates

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[4]See Murphy and Topel (2003, 2006) for a discussion of the theoretical predictions concerning the valuation of mortality changes.

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observed for males.

The contribution of this paper is twofold. First, it adds to the empirical evidence on the welfare costs associated with EVD and other infectious diseases (Philipson and Soares, 2005; Fimpel and Stolpe, 2010). To the author's knowledge, no other papers have estimated the welfare costs of the EVD crisis using the WTP approach. Furthermore, previous studies have not accounted for the upper and lower bounds of the confidence intervals for age-specific survival probabilities, which capture uncertainties regarding the true impact of EVD. Second, the results suggest that the approaches taken by Kirigia et al. (2015) and Huber et al. (2018) may under and over estimate the true welfare losses due to EVD-related mortality, respectively. Incorporating additional information on age, sex and consumption seems to improve the estimation of such costs.

The structure of the paper is as follows. Section 2 introduces the WTP approach to valuing changes in mortality and discusses the underlying assumptions. Section 3 provides an overview of the household survey and demographic datasets. Section 4 presents the results of the analysis alongside some sensitivity checks. Section 5 discusses the strengths and weaknesses of the approach and Section 6 concludes.

2 Valuing mortality changes

2.1 General model

There is a robust literature exploring the WTP for reductions in mortality from the theoretical and empirical perspectives (Schelling, 1968; Usher, 1973; Arthur, 1981; Rosen, 1988; Becker et al., 2005; Murphy and Topel, 2006). The theory suggests that the WTP for reductions in mortality is determined by how such changes affect the discounted present value of expected lifetime utility. Using the intertemporal model of Yaari (1965), expected lifetime utility of an individual aged a can be defined as a discounted sum of period utilities $u(c(t))$, which depend on consumption $c(t)$ at time t, weighted by the force of discounting p and the probability of being alive up to that period, given by the survival function $S(t,a)$[5]:

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[5]It is assumed that individuals are expected utility maximisers over lotteries of lives, where the survival probabilities determine the probability of different lengths of life. The model presented here is based on Cerqueira and Soares (2016).

$$U(a) = \int_a^\infty u(c(t))e^{-p(t-a)}S(t,a)dt \,. \tag{1}$$

If there exists a complete contingent claims market,[6] so that the expected discounted value of future consumption equals expected wealth (see Yaari, 1965), the individual's lifetime budget constraint can be written as:

$$A(a) + \int_a^\infty [y(t) - c(t)]e^{-r(t-a)}S(t,a)dt = 0 \,, \tag{2}$$

where $A(a)$ is accumulated wealth at age a, $y(t)$ is life contingent income in period t and r is the interest rate. Assuming that the individual chooses $c(t)$ to maximise (1) subject to (2) yields the following value function:

$$V(a) = \int_a^\infty \left\{ u(c(t))e^{-p(t-a)} + \lambda_a[(y(t) - c(t))\,e^{-r(t-a)}] \right\} S(t,a)dt + \lambda(a)A(a) \,, \tag{3}$$

where λ_a is the Lagrange multiplier on the constraint for an individual aged a. Optimal choices of consumption in each period t lead to the first order condition described in Equation (4):

$$u'(c(t))e^{-p(t-a)} = \lambda_a e^{-r(t-a)} \,, \tag{4}$$

for every t, where $u'(c(t))$ is the marginal utility of consumption in period t. Note that the optimising choice is independent of the survival conditions due to the complete contingent claims market assumption.[7]

It follows that the WTP for some change in the survival function at age a due to an exogenous factor θ (e.g. the outbreak of EVD) is then:

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[6]That is, a system in which actuarially fair life-assured annuities are available. A cohort of individuals hand their wealth over to an insurance company in exchange for a contract that guarantees consumption $c(t)$ until death. Thus, the consumption risk of death is insured because those who die in periods below the average 'subsidise' the consumption claims of those who live beyond the average and the model does not consider utility derived from bequests. This is a standard assumption within the economics of mortality literature.

[7]Relaxing this assumption has an ambiguous effect on the final WTP values. On one hand, removing annuity markets lowers lifetime utility (Yaari, 1965). On the other hand, eliminating such markets forces individuals to shift their consumption to earlier periods of life since consumption allocated to later periods may not be enjoyed. This increases utility in earlier periods, which are subject to lower discount factors. See Bauer et al. (2018) for a discussion.

$$WTP_a = \frac{\partial V(a)}{\partial S(t,a)} \frac{\partial S(t,a)}{\partial \theta} \frac{1}{\partial V(a)/\partial A(a)} = \frac{\partial V(a)/\partial \theta}{\lambda_a} \; . \qquad (5)$$

Using the envelope theorem and the first order condition from Equation (4), this formula can be re-written as:

$$WTP_a = \int_a^\infty \left[\frac{u(c(t))}{u'(c(t))} + y(t) - c(t) \right] e^{-r(t-a)} S_\theta(t,a) dt \; , \qquad (6)$$

where $S_\theta(t,a)$ denotes the change in the survival function due to the EVD. Equation (6) shows that an individual's marginal WTP at age a depends on four factors. First, the higher an individual's consumption level, and thus the direct utility gain from a period of life $u(c(t))$, the greater the WTP for a change in survival conditions, *ceteris paribus*.[8] Second, discounting of the future, captured by the term $e^{-r(t-a)}$, suggests that the closer an individual is to the period where a mortality increase takes place, the more he/she is willing to pay to avoid it. Third, the income surplus in a period $y(t) - c(t)$ determines the value of increasing survival up to that point as it can be used to subsidise consumption in other periods. Lastly, the WTP will depend on the magnitude of the change in the survival function $S_\theta(t,a)$, with larger changes leading to higher WTP values, *ceteris paribus*.

To make the model tractable, it is assumed that the rate of time preference p is equal to the interest rate r and that each individual enjoys his or her current consumption in all remaining periods of life. The first order conditions at the individual's optimum therefore imply that $c(t)$ is also constant over time, that is $c(t) = c = y$ (i.e. perfect consumption smoothing). The individual WTP_a in Equation (6) then becomes:

$$WTP_a = u(c)/(u'(c)) \int_a^\infty e^{-r(t-a)} S_\theta(t,a) dt \; . \qquad (7)$$

To derive the society's WTP for changes in survival probabilities due to the EVD, the individual WTP_a values are aggregated across a, using the respective population sizes for each age group as weights:

$$SWTP = P \int_0^\infty WTP_a f(a) da \; , \qquad (8)$$

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[8]The term $u(c(t))/u'(c(t))$ can be interpreted as the value of a period of life in consumption units.

where P is the population of a country which is distributed across ages according to the density function $f(a)$. This approach implicitly assumes that there is a time invariant population distribution across a and disregards the willingness to pay of future unborn generations for reductions in mortality.

2.2 Calibration

The above discussion leaves the precise form of the instantaneous utility function unspecified. In line with the literature, it is assumed that this function is of the constant relative risk aversion type (Becker et al., 2005; Murphy and Topel, 2006; Hall and Jones, 2007):

$$u(c) = \frac{c^{1-1/\gamma} - c_0^{1-1/\gamma}}{1 - 1/\gamma} \; , \tag{9}$$

where utility is determined by three factors: current consumption c, the intertemporal elasticity of substitution γ and some subsistence level of consumption c_0. Note that instantaneous utility increases with the level of consumption, which implies a larger willingness to pay for improvements in survival conditions. The intertemporal elasticity of substitution γ determines the curvature of the instantaneous utility function and plays a similar role to risk aversion in the single period model. As a general rule, a lower value of γ implies a greater willingness to pay for improvements in survival conditions.[9] The parameter c_0 arises because of the normalisation of the death state to zero and defines the level of consumption at which an individual would be indifferent between being alive or dead (see Rosen, 1988). A higher level of subsistence consumption leads to a lower level of utility and thus reduces the willingness to pay for improvements in survival conditions.

Since there is a lack of evidence on the value of statistical life (VSL) and elasticity of intertemporal substitution in Liberia,[10] the preference parameters in Equa-

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[9]As γ tends to ∞, consumption at any one time period becomes a very good substitute for consumption in another time period. An individual with such preferences will be less willing to pay for improvements in survival conditions because any increase in utility arising from an extension of life expectancy will be negated by lower per period consumption. When γ goes to zero, the indifference curves between consumption in two periods start to coincide with those of fixed proportions. Thus, an individual with such preferences will be willing to pay more for an increase in survival conditions because each year of life becomes essential in improving expected lifetime utility. See Rosen (1988) for a more thorough discussion of these points.

[10]In the neighbouring country Sierra Leone, León and Miguel (2017) estimate the VSL by exploiting variation in risky transport choices. However, their analysis focuses on relatively rich African and international travellers.

tion (9) are set equal to those used by Becker et al. (2005). While the authors use a different specification for instantaneous utility, Equation (9) is sufficiently flexible to accomodate their calibration. Thus, the values of γ and c_0 are set to 1.25 and \$353, respectively. The former value is based on an exhaustive review of the empirical literature by Browning et al. (1999), who suggest that the intertemporal elasticity of substitution with respect to consumption is slightly above unity. The latter is derived from labour market studies of the VSL and is implied by the calibration of Becker et al. (2005).[11] Finally, the interest rate, r, is set conservatively at 12%.[12] Note that the force of mortality, through $S(t, a)$, also makes an individual weight the future less heavily, i.e., it represents a biological discount rate.

Using this parameterisation, the individual WTP_a in Equation (7) becomes:

$$WTP_a = \frac{\gamma}{\gamma - 1} \left(\frac{c^{1-1/\gamma} - c_0^{1-1/\gamma}}{c^{-1/\gamma}} \right) \int_a^\infty e^{-r(t-a)} S_\theta(t, a) dt \,, \qquad (10)$$

where the first term reflects the consumption value of being alive relative to being dead, and the second term gives the aggregated discounted survival gains over the remaining years of life. This equation is used to estimate welfare change throughout the rest of the paper.

3 Data

3.1 Household survey

The consumption expenditure data used in this paper are taken from the Liberia Household Income and Expenditure Survey (HIES) 2014-2015. The HIES is nationally representative and covers 8,360 randomly selected households containing 18,079 individuals. It provides information on aggregate household consumption expenditures across a series of items, which are used to update several national statistics, such as the consumer price index, and poverty rate.[13] To

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[11]Becker et al. (2005) use an estimate of the consumption elasticity of the instantaneous utility function from Murphy and Topel (2003). Based on evidence from Viscusi (1993), they assume that an individual is willing to pay \$500 to reduce the annual probability of death by 1/10,000, which implies $\varepsilon = 0.346$. Using this estimate of ε along with the intertemporal elasticity of substitution γ, suggests $c_0 = \$353$.

[12]This interest rate is commonly used by the World Bank to assess projects in developing countries and almost the same as the average Liberian benchmark interest rate in 2014.

[13]The dataset is compiled by Liberia Institute for Statistics and Geo-Information Services (LISGIS). A full overview of the methodology at:

		Median	Std. Dev.	Min	Max	n
	Males	609	469	76	12,459	8,919
Consumption	Females	618	464	76	5,451	9,160
	Total	611	466	76	12,459	18,079

Notes: Adult equivalent weighted statistics. Consumption values are reported in US$ per capita and rounded.

Table 1: Summary statistics, Liberia 2014

take into account the household composition, equivalence scales provided by the HIES are used to calculate per adult equivalent consumption expenditures. These scales adjust for differences in requirements by age as well as sex.[14]

The HIES was halted in August 2014 after a state of emergency was declared in the country due to the outbreak of EVD. Thus, the consumption values are unlikely to be confounded by the effects of EVD (e.g. reduced incomes). However, the sudden halt meant that the data collection period coincided with the lean season in Liberia, when food consumption levels are expected to be at their lowest. This means that the estimates of the total welfare costs of EVD presented in this paper will be to some extent downwardly biased (recall that individual WTP depends on the individual's consumption level).

Table 1 presents the key summary statistics on consumption for both sexes.[15] As shown in the previous section, these two variables play an important role in determining the WTP for changes in survival conditions. The median consumption expenditure level per adult equivalent in the sample is $611. Per adult equivalent consumption expenditure levels for males and females are relatively similar at $609 and $618, respectively. Note that these values do not capture the distribution of consumption expenditures within the household. Instead, all individuals in a particular household are assumed to enjoy the same consumption level per adult equivalent. This explains why males and females have identical minimum consumption expenditures in Table 1. Such biases should be considered when drawing conclusions on the distribution of welfare costs by sex in this paper.

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http://microdata.worldbank.org/index.php/catalog/2563

[14]LISGIS (2016) states that these equivalence scales are based on the standard FAO scales derived for Guinea in 2004 and are therefore considered appropriate for the West African context. Note that per capita consumption measures

[15]The raw data is provided in Liberian dollars and these figures are adjusted to nominal US dollars using a rate of 86.75 Liberian dollars/$US dollar, which is an approximation of the unofficial exchange rate during the data collection period. This figure is provided by the Liberia Institute of Statistics & Geo-Information Services in the accompanying Household
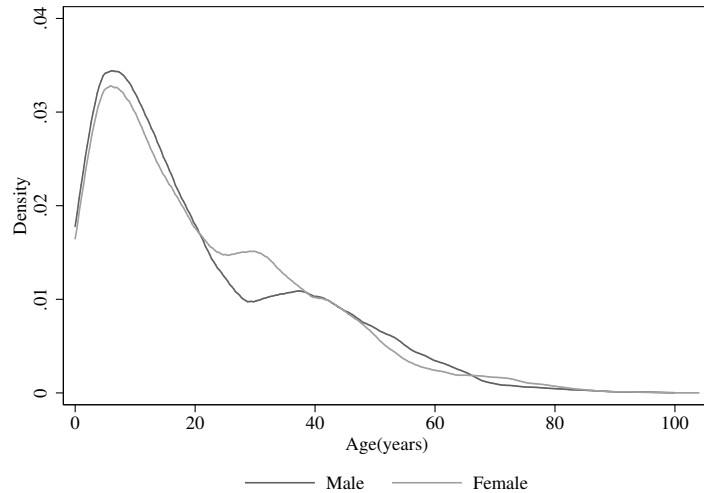
Figure 1: Age distribution (weighted), males and females

Figure 1 shows that there are some differences in the age distributions of males and females, occuring around the 20-35 years age group. This could reflect differences in baseline mortality between the two groups that occur at reproductive ages, for instance, due to diseases such as HIV/AIDS. These differences in the age distribution may be important given that the WTP for changes in survival conditions depends on an individual's proximity to the point in time where such changes occur.

3.2 Mortality data

Mortality rates disaggregated by cause, age group and sex are taken from the Institute for Health Metrics and Evaluation (IHME, 2018) for the year 2014. These data are used to construct actual and counterfactual survival functions, the latter reflecting a scenario that excludes deaths from EVD. Three scenarios are modelled within this paper. The baseline EVD scenario is derived from the IHME point estimates of mortality. These point estimates are also provided with a 95% confidence interval, the bounds of which are used to create the high and low EVD scenarios.

Income and Expenditure Report (LISGIS, 2016).

3.2.1 Measurement error

Measurement error is an immediate concern with any indicator of mortality in developing countries due to inefficient death registration systems. For instance, the Liberian Ministry of Health reports that death registration coverage has always been below 5% annually.[16] Furthermore, many cases of EVD may not have been reported at all. Meltzer et al. (2014), for example, estimate that the number of EVD cases may have been 2.5 times greater than the number actually reported across all affected countries, by the end of 2014. The IHME uses a variety of modelling techniques to generate plausible figures for adult mortality in low income countries. In the case of EVD deaths, the IHME uses actual and modelled figures as inputs and applies a correction factors for under-reporting.[17]
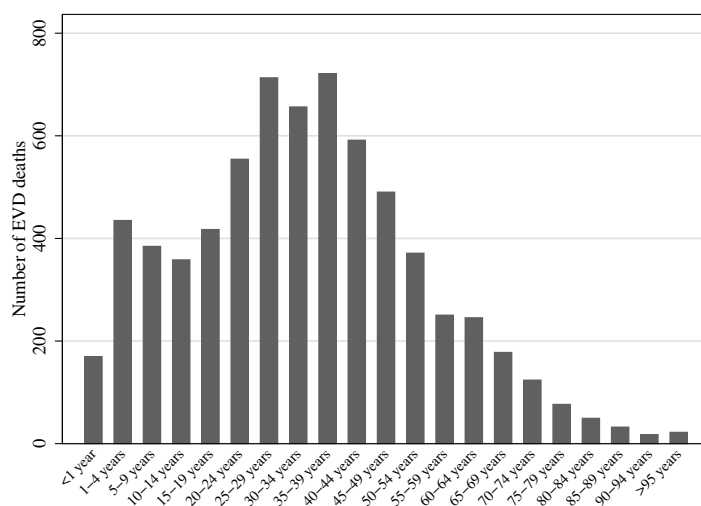

Figure 2: Number of EVD deaths in Liberia (males and females), 2014. Source: IHME (2018)

The estimated number of deaths due to EVD are displayed in Figure 2. The IHME estimates suggest that there were 6,861 deaths in Liberia directly caused by EVD, which is much higher than the total 4,806 confirmed deaths reported

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[16]Information accessed [10/05/19] at: http://moh.gov.lr/death-registration/

[17]However, the magnitude of the correction factor is not stated explicitly in the metadata. A full overview of the IHME estimation methodology can be found at: http://ghdx.healthdata.org/gbd-2017/code [accessed 10/07/19]

by the WHO and cited in the introduction of this paper. The data suggest that the largest number of deaths occurred between the ages 25 to 39 years, with these ages alone accounting for 30% of all deaths caused by EVD.

3.2.2 Calculating the survival function

To compute the conditional survival function, the probability of survival between ages t and $t+1$ is derived from the mortality data as follows:

$$s_{(t,t+1)} = 1 - d_{(t,t+1)}/n_t = 1 - \mu_{(t,t+1)} \ ,$$

where $d_{(t,t+1)}$ is the number of deaths within this age interval, n_t is the number of individuals alive at age t and $\mu_{(t,t+1)}$ is the probability of death. The counterfactual survival probabilities that would have been realized in the absence of EVD are calculated as:

$$s'_{(t,t+1)} = 1 - \left[d_{(t,t+1)} - \tau_{(t,t+1)}/n_t \right] \ ,$$

where $\tau_{(t,t+1)}$ is the number of deaths directly attributable to EVD between the ages t and $t+1$ and $s'_{(t,t+1)}$ is the counterfactual no-EVD survival probability within this interval. The conditional survival functions for the actual and counterfactual scenarios are then given by the products of these individual survival probabilities for an individual aged a and with lifetime t, which are $S(t,a) = \prod_a^{t-1} s_{(i,i+1)}$ and $SNE(t,a) = \prod_a^{t-1} s'_{(i,i+1)}$, respectively.[18] The change in the survival function due to the impact of EVD on mortality is then:

$$S_\theta(t,a) = SNE(t,a) - S(t,a) \ .$$

Furthermore, the life expectancy at birth in each scenario can be defined as the integral under the survival function or in the discrete setting $L = \sum_{t=1}^{\infty} S(t,0)$. The number of life years lost to EVD can then be derived as the difference between the life expectancy at birth in the actual and counterfactual scenarios or:

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[18]More specifically, the mortality data is disaggregated by 5-year age intervals meaning that some assumption is required on the force of mortality within each age interval. We follow the method used by Fergany (1971) due to its simplicity and parsimonious data requirements.

$$L_\theta = \sum_{t=1}^{\infty} SNE(t,0) - \sum_{t=1}^{\infty} S(t,0)$$

3.2.3 Heterogeneity in survival probabilities

The available mortality data allows for the derivation of the respective survival functions and number of life years lost due to EVD for each sex. However, the data does not permit the derivation of a survival function that varies by other socio-economic characteristics. More specifically, each individual is expected to live the average length of life of his or her sex, regardless of other characteristics. This may obscure important heterogeneities in survival conditions, for instance, between rich and poor individuals. The implications of this assumption for the WTP estimates are unclear because Equation 10 shows that the WTP depends on several other factors aside from the magnitude of the change in survival conditions given by $S_\theta(t,a)$, such as the level of consumption and age of the individual. Previous evidence suggests that neglecting heterogeneities in survival rates can downwardly bias the WTP estimates. Cerqueira and Soares (2016), for instance, find that ignoring differences in survival rates due to gender, education and state of residence leads to WTP estimates that are 23% lower than those based on survival functions that consider all these dimensions simultaneously. Unfortunately, without more accurate mortality data, survival curves cannot be estimated for different socio-economic groups in Liberia during 2014. The individual and total WTP values presented in this paper should therefore be interpreted as the respective amounts of consumption an individual and society would be willing to forego in order to avoid the increase in mortality rates induced by EVD at the population level.

4 Results

4.1 Mortality change

Figure 3 presents the actual and counterfactual survival functions for males and females, using the baseline survival probability estimates. The shift in the survival function represents the impact of EVD on mortality and is evident for both sexes. The area between the two curves corresponds to the loss of life expectancy due to EVD. Note that the gap between the actual and counterfactual
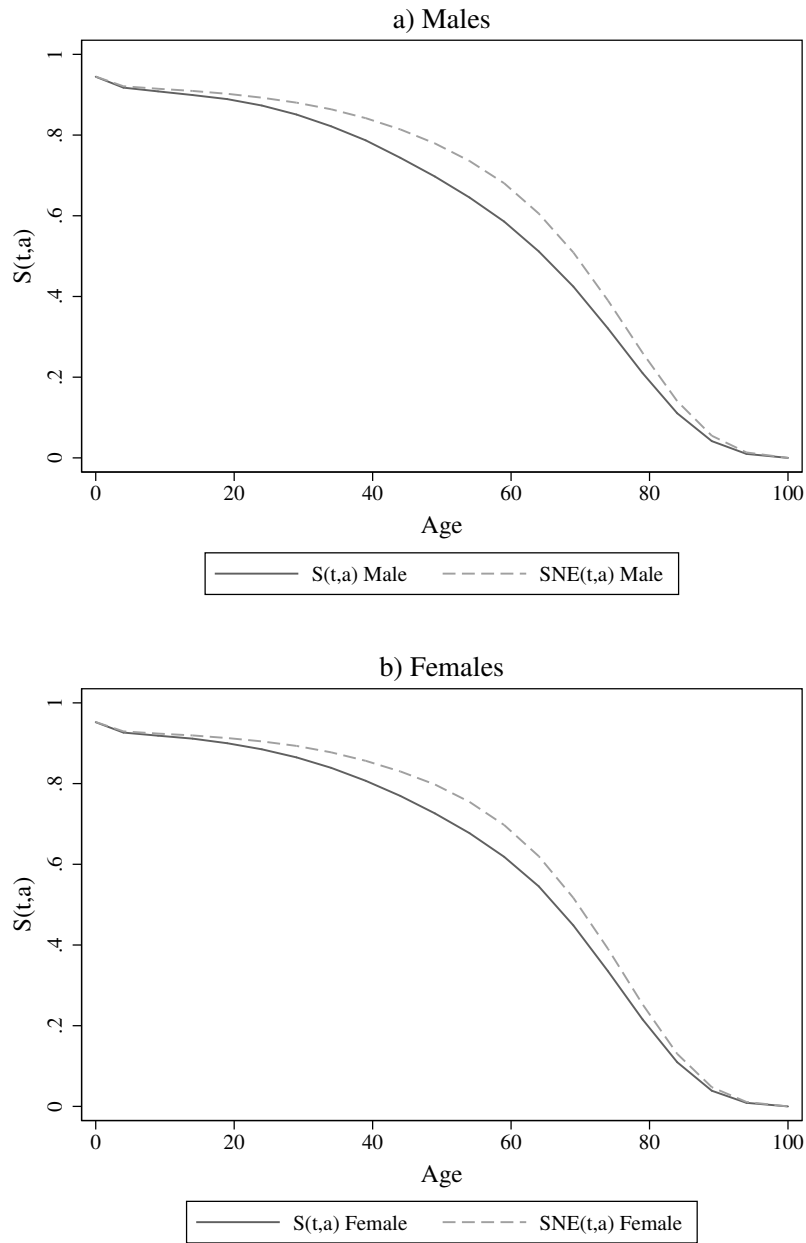
a) Males

b) Females

Figure 3: Actual and counterfactual survival functions by sex: Liberia, 2014.
Source: author's own calculations using data from IHME (2018).

Group	Estimate	(1) Life expectancy 2014	(2) Life expectancy (no-EVD)	(3) Life years lost to EVD
Male	Upper	56.1	61.3	5.2
	Baseline	58.5	62.8	4.3
	Lower	60.9	64.3	3.4
Female	Upper	57.8	62.1	4.3
	Baseline	60.0	63.6	3.6
	Lower	62.5	65.3	2.8
Total	Upper	57.1	61.9	4.8
	Baseline	59.2	63.2	3.9
	Lower	61.5	64.5	3.1

Notes: author's own calculations based on estimates from the IHME (2018).

Table 2: Impact of EVD on life expectancy

survival functions is slightly larger for males than for females. The estimates suggest that EVD has reduced life expectancy for males and females by 3.4-5.2 years and 2.8-4.3 years respectively (see Table 2). These estimates appear to be in line with figures from previous works. Helleringer and Noymer (2015), for instance, also model three scenarios[19] and find that the EVD outbreak has reduced life expectancy by between 1.63 to 5.56 years in Liberia (for both sexes).

Another pertinent feature of Figure 3 is the age distribution of mortality. The largest gap between the actual and counterfactual survival function occurs during adulthood and not at early ages. This suggests that the impact of EVD on mortality was greatest at these ages, which has consequences for the measure of overall welfare change. Recall that an individual is willing to pay more for a reduction in mortality rates, the closer he or she is to the point in time where the change in mortality occurs due to discounting of the future. This means that older or middle aged adults will be willing to pay more to avoid the mortality impacts of EVD relative to their younger or older counterparts, *ceteris paribus*.

To illustrate this point more clearly, Figure 4 presents the individual WTP for changes in survival conditions as a function of age using Equation (10). This curve is derived for a representative individual enjoying the average consumption level and survival conditions of his or her sex in each period of life from their current age until death. The WTP starts off relatively low for young individuals and then steadily increases until it reaches a maximum at around age 50 for

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[19]A high, medium and low scenario based on different assumptions regarding the underreporting of Ebola cases and the Ebola case fatality ratio.

males and age 45 for females. Thereafter, the WTP falls until it reaches almost zero for the very elderly. This pattern coincides with the timing of the mortality increases. For children and young adults, these mortality increases are far off in the future and are therefore discounted more heavily leading to a lower WTP. For middle-aged individuals, the timing of the mortality change is more imminent and therefore leads to a higher WTP.
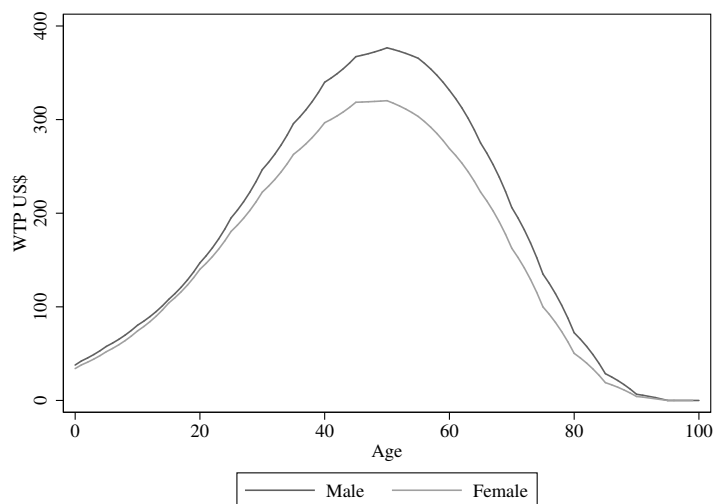

Figure 4: Individual WTP as a function of age.

4.2 The mortality related welfare costs of EVD

Table 3 presents the results of the welfare analysis using Equations (8) and (10). Column (1) gives the average individual WTP to avoid the EVD outbreak across the population, which varies at the individual level by consumption level, sex and age. The total WTP to avoid EVD-related mortality increases (see Equation 8) is given in column (2) and the last column presents this value as a proportion of Liberia's total GDP in 2014.[20] Two key findings can be drawn from the table. First, the total costs of EVD are around $2.5 billion under the most conservative estimation (see lower estimate). This figure increases to approximately $4 billion when we use the upper bound of the confidence interval for EVD mortality rates, as estimated by the IHME. Taking the baseline estimate of $3.2 billion suggests

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[20]The GDP of Liberia in 2014 was $3.144 billion according to World Bank Data. Accessed [09/05/19] at: https://data.worldbank.org/country/liberia

Group	Estimate	(1) Average WTP	(2) Total WTP ($ millions)	(3) % of GDP
Male	Upper	249	2,110	68.1
	Baseline	204	1,730	55.8
	Lower	157	1,330	42.9
Female	Upper	213	1,860	60
	Baseline	173	1,510	48.7
	Lower	132	1,150	37.1
Total	Upper	231	3,970	128.1
	Baseline	188	3,240	104.5
	Lower	144	2,480	80.0

Notes: author's own calculations based on estimates from the IHME (2018). All values are in $US. Weighted population averages.

Table 3: WTP to avoid EVD-related mortality changes

that the total costs of EVD amount to approximately 105% of Liberia's GDP in 2014.[21] While these costs may seem large, they seem to be in line with previous findings in the literature for other diseases. For instance, Philipson and Soares (2005) estimate that the total costs of HIV/AIDS amount to 96% of the Sub-Saharan African region's GDP while in some of the worst affected countries this figure is more than 200% (e.g. Botswana). Second, the estimates suggest that the total costs of EVD-related mortality are higher for males than for females. For instance, this difference is around $0.2 billion using the baseline mortality estimates (see central in Table 3). This result seems to be driven by the differences in mortality rates between the two groups given that the age distributions and average consumption levels are relatively similar for males and females in the sample. The sampling weights also imply that there are more females than males in Liberia, which would have a mitigating effect on the difference in this framework.

There are three salient features of the analysis that make the estimates rather conservative. First, the analysis is restricted to the year 2014 as the HIES data collection period finished before 2015, due to the EVD outbreak. Taking into account the additional (but reduced) mortality impacts in 2015 would lead to a small increase in the total welfare costs. Second, the results do not capture the additional indirect deaths that may have resulted from disruption to the health service. For instance, Parpia et al. (2016) estimate that the EVD out-

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[21]Liberia's GDP (current $US) was around $3.1 billion in 2014 according to World Bank estimates.

break led to between 522-2,870 additional malaria, HIV/AIDS and tuberculosis deaths in Liberia during 2014-15. Without further information on the age and gender profile of these deaths, they cannot be incorporated into the analysis. Nevertheless, one would expect that the total welfare costs to rise considerably, as indicated by Huber et al. (2018). Finally, although the aim of this paper is to capture mortality-related welfare losses, it should be stressed that the figures above hold consumption constant across both scenarios, that is they do not account for the impacts of EVD on the distribution of consumption expenditures. One would expect the total welfare costs of EVD to be greater once changes in consumption were accounted for.

4.3   Sensitivity checks

Although the model above is relatively flexible in that it permits WTP values to vary with consumption levels, the empirical evidence on certain parameters is far from conclusive. For instance, studies show that the intertemporal elasticity of substitution γ may vary considerably across countries, demographics and with wealth (Browning et al., 1999; Havranek et al., 2015). Moreover, opportunities in developing countries for intertemporal substitution of consumption may be limited because poorer households devote a larger share of their budgets to necessities, which are difficult to substitute across periods (Ogaki et al., 1996). Such findings are important, given that a lower elasticity of intertemporal substitution leads to a higher willingness to pay for additional life years, *ceteris paribus* (see Rosen, 1988).

While the necessary micro-level data to estimate the parameters of the model are unavailable, one can still test the robustness of the results using different preference parameters. In this section, the results are re-estimated using different values for γ and c_0. For ease of exposition, the results are presented for only the baseline survival scenario and for both sexes combined.[22] In addition, the discount rate is not varied because the force of mortality through $S(t, a)$ makes an individual discount the future more heavily anyway. Thus, assumption of such high interest rates may be overly strong.

The flexibility of the utility function in Equation (9) allows for the sensitivity of the results to be tested with two approaches alongside a range of values for

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[22]Estimates of costs for the upper and lower bounds of the changes in survival functions are available upon request.

γ:[23] i) using different absolute values of c_0; or ii) allowing c_0 to vary with each consumption level. For instance, Becker et al. (2005) assume that the value of subsistence consumption c_0 is invariant across individuals and socio-economic contexts, that is a representative individual would be indifferent between living a life with a constant annual income of \$353 and death. Since there is little empirical evidence on this value, one can conduct a sensitivity analysis using different absolute values of c_0. Alternatively, it may be the case that the value of c_0 varies with or remains proportional to individual consumption levels. Murphy and Topel (2006), for instance, test the robustness of their results using different relative values of c_0 for all individuals. Under such preferences, an individual with a higher consumption level would be indifferent between life and death at a greater value of c_0 than his or her poorer counterparts, *ceteris paribus*. To test the robustness of the results, both of these approaches are now presented in turn.

Figure 5 presents the results of the sensitivity analysis using three absolute values of c_0 in combination with several different values of the elasticity of intertemporal substitution. The vertical solid line represents the baseline value of $\gamma = 1.25$. The uppermost curve is generated using the baseline value of $c_0 = \$353$ from the analysis above. The results show that raising γ beyond the baseline value of 1.25 used in the main analysis does not lead to large reduction in the total welfare costs. At the highest value of $\gamma = 2$, these costs still amount to \$2.7 billion. The middle curve is based on a more conservative value of $c_0 = \$428$, which was the food poverty line in Liberia during 2014 (LISGIS, 2016). This amounts to assuming that all individuals with consumption levels under the food poverty line in 2014 have negative utility in all remaining periods of live. Under this assumption, the total welfare costs still remain large at all levels of γ and above \$2.2 billion at $\gamma = 2$. The bottom most curve in Figure 5 is based on the most conservative assumption that $c_0 = \$754$, which was the overall poverty line in Liberia during 2014 (LISGIS, 2016). This assumption is rather extreme since it suggests that death is a good rather than a bad for all individuals living under the poverty line. Nevertheless, the total welfare costs associated with EVD remain positive and still sizeable within the Liberian context. For instance, the most conservative calibration ($\gamma = 2$) suggests that the welfare costs of EVD are around \$0.3 billion, which is still almost 10% of

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[23]A third approach used in the literature is to assume $c_0 = 0$, that is there is no minimum consumption level where an individual is indifferent between life and death (see Usher 1973; Crafts and Haacker 2003).
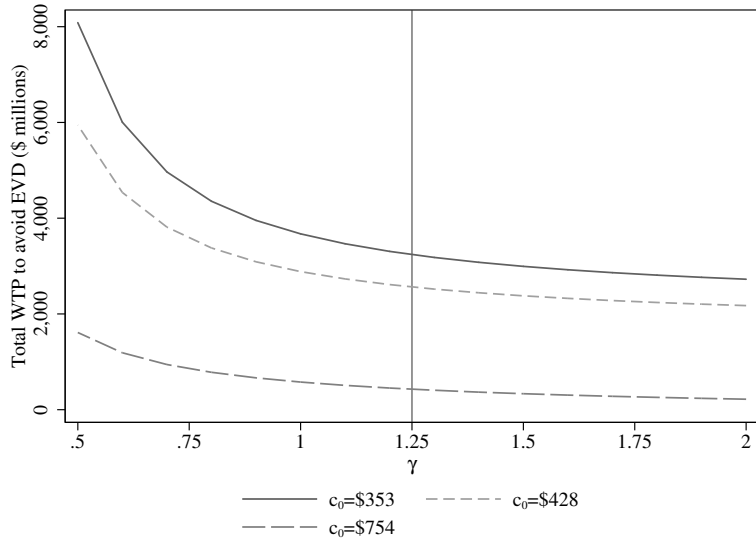
Figure 5: Total WTP to avoid EVD-related mortality changes with different *absolute* values of c_0
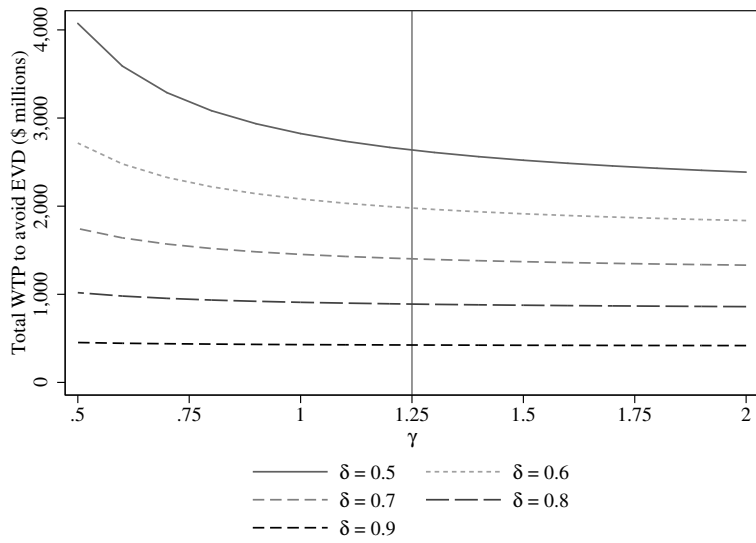

Figure 6: Total WTP to avoid EVD-related mortality changes with different *relative* values of c_0

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Liberia's total GDP in 2014.

Figure 6 presents the results of the second approach using relative values of $c_0 = \delta c$, where δ is the proportion of consumption that makes an individual indifferent between live and death. The values of δ start from 0.5 as this value corresponds closely to the baseline estimates using the calibration of Becker et al. (2005), at the aggregate level. Note that lower values of δ imply greater total welfare costs of EVD. The figure shows that the total welfare costs are relatively sensitive to changes in the proportional value of δ but the costs still remain high in the Liberian context (i.e. relative to total GDP). At $\delta = 0.7$, the total welfare costs of EVD are around \$2 billion using the most conservative parameterisation ($\gamma = 2$). Going much further and assuming that all individuals would be indifferent between life and death at a value with 90% of their current consumption ($\delta = 0.9$), yields total costs that are around \$0.4 billion. Hence, even using the most conservative specifications, the sensitivity analysis suggests that the mortality related welfare costs of EVD are still comparable and larger in magnitude than the economic estimates provided by the UNDG (2015) and World Bank (2016), which are based on changes in income alone.

5 Discussion and policy implications

This section highlights some of the strengths and weaknesses of the WTP approach employed within this paper. One of the key advantages of the approach is that it approximates the value that individuals place on their own life and continued living using empirical evidence on key preference parameters. This contrasts with other approaches that value mortality increases in terms of foregone economic output (e.g. Kirigia et al., 2015). The results above suggest that such an approach underestimates the true costs of EVD-related mortality since it fails to capture the non-consumption benefits of living longer. Second, the framework above considers heterogeneities in consumption and survival probabilities as well as the age structure of the population when estimating the total WTP to avoid the EVD outbreak.

The ex-ante approach applied within this paper differs from the standard ex-post approach used in cost benefit analysis, which applies a fixed VSL to all deaths regardless of age, consumption level or sex. Taking into account such information suggests that previous estimates based on a fixed VSL overestimate the true cost of EVD. To highlight this further, one could follow the methodology

of Huber et al. (2018) and apply a fixed VSL of $577,000 to the 6,861 estimated EVD deaths in Liberia, which is the number of deaths considered in the baseline analysis of this paper. This yields a total cost of EVD-related mortality of around $4 billion, which is over $0.7 billion higher than the central estimate and not trivial given the extremely low incomes under analysis.[24]

A key criticism that could be levied against the baseline analysis is the reliance on preference parameters derived from labour market evidence in developed countries. Unfortunately, without further evidence on the VSL and intertemporal elasticity of substitution in Liberia, such approaches are unavoidable. Despite these criticisms, three arguments can be forwarded in favour of the framework and parameters adopted. First, as mentioned above, the framework is flexible in that it allows the WTP for changes in mortality to vary with consumption level. Second, previous papers have used the same calibration to assess the welfare costs of diseases in West African countries, such as Guinea and Sierra Leone (see Philipson and Soares, 2005), and the evolution of welfare inequality across developed and developing countries (e.g. Becker et al., 2005). Adopting these parameter values therefore allows for comparability with these studies. Third, the sensitivity analysis suggests the calibration may be rather conservative in the Liberian context. As stated above, individuals with lower incomes may have a lower elasticity of intertemporal substitution relative to those with higher incomes. A recent meta-analysis of 169 studies by Havranek et al. (2015) lends evidence to support this suggestion and estimates an the average value of $\gamma = 0.5$ across all countries. Thus, the assumption of γ greater than unity may be overly strong (note that lower values of γ would imply a greater WTP to avoid the outbreak of EVD as shown in the sensitivity analysis).

Overall, the magnitude of costs presented in this paper highlights the need to strengthen the resilience of the healthcare system in Liberia to mitigate the impacts of future outbreaks of EVD and other infectious diseases. This necessitates investments in key healthcare infrastructure and personnel, which Liberia is still severely lacking. For instance, there were only 168 medical doctors in Liberia for a popuation of 4.5 million people in 2015.[25] The estimates presented in this paper contribute to the growing quantitative evidence on the costs of inaction for the future. This evidence is relevant for both domestic and international

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[24]To highlight this point further, the World Bank states that Liberia's GDP was $3.1 billion (current $US) in 2014.

[25]WHO data, accessed [10/05/19] at:
http://apps.who.int/gho/data/node.main.HWFGRP_0020?lang=en

policy makers, as the EVD epidemic has shown how a tropical disease can rapidly spread both within and between countries, including to the US and UK. In addition, one could tentatively view the results as an indication of the potential benefits from future research into and development of an EVD vaccine, which is currently being trialled in several countries, including Liberia.

6 Conclusions

The main objective of this paper has been to quantify the welfare costs of the EVD crisis in Liberia using a WTP methodology that accounts for differences in individual consumption levels and heterogeneities in survival between males and females. As such, this work builds on previous estimates of the costs of EVD, which have predominantly focused on economic costs and lifetime productivity losses. The results suggest that the magnitude of the welfare costs far outweighs those based on income alone, providing further impetus to take a multidimensional approach to welfare measurement. Moreover, the results indicate that the EVD crisis had a larger impact on males than on females, when attention is restricted to mortality impacts alone. That is not to say that males have suffered unequivocally more than females. The study only captures changes in one relevant aspect of welfare (mortality) and does not consider other impacts that may be specific to females. For instance, it is estimated that maternal mortality rates increased due to a shortage of healthcare workers that died from the virus (Evans et al., 2015).

Future empirical work will benefit from further empirical evidence on key preference parameters when more VSL studies are carried out in developing countries. One possibility would be to estimate preference parameters over consumption and mortality directly using expanded household datasets. Murtin et al. (2017) provide an interesting approach to this problem using life satisfaction data to estimate the WTP for improvements in survival conditions. This paper has also shown that heterogeneities in consumption and survival conditions across the population are a relevant factor in the calculation of welfare costs, even when differences in the latter are restricted to two groups (e.g. male and female). Again, micro-level data could be used to estimate survival curves that vary due to gender, education and area of residence, all of which would contribute to a more accurate estimation of the society's total WTP to avoid infectious diseases, such as EVD.

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