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Economic Costs of Childhood Lead Exposure in Low- and Middle-Income Countries

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Abbreviations: BLL (blood lead level); CDC (Centers for Disease Control and Prevention); IQ (intellectual quotient); LEP (lifetime economic productivity); LMICS (low-middle income countries); MMR (mild mental retardation); SD (standard deviation).

Abstract

Background: Children's blood lead levels have declined worldwide, especially after the removal of lead in gasoline. However, significant exposure remains, particularly in low- and middle-income countries. To date, there have been no global estimates of the costs related to lead exposure in children in developing countries.

Objectives: Our main aim was to estimate the economic costs attributable to childhood lead exposure in low- and middle-income countries.

Methods: We developed a regression model to estimate mean blood lead levels in our population of interest, represented by each 1-year cohort of children under 5 years of age. We used an environmentally attributable fraction model to estimate lead-attributable economic costs and limited our analysis to the neurodevelopmental impacts of lead, assessed as decrements in intellectual quotient (IQ) points. Our main outcome was lost lifetime economic productivity due to early childhood exposure.

Results: We estimate a total cost of $977 billions of international dollars in low- and middle-income countries, with economic losses equal to $134.7 billion in Africa (4.03% of GDP), $142.3 in Latin America and the Caribbean (2.04% of GDP), and $699.9 in Asia (1.88% of GDP). Our sensitivity analysis indicates a total economic loss in the range of $728.6-1,162.5 billion.

Conclusions: We estimate that, in low- and middle-income countries, the burden associated with childhood lead exposure amounts to 1.20% of world GDP in 2011. For comparison, US and Europe lead-attributable economic costs have been estimated at $50.9 and $55 billion,

respectively, suggesting that the largest burden of lead exposure is now borne by low- and middle-income countries.

Introduction

The removal of lead from gasoline is perhaps one of the greatest public health accomplishments, and arguably produced some of the largest reductions in pediatric morbidity, over the past fifty years. As a result of an aggressive international campaign by the United Nations Environment Programme, today only six countries continue to use leaded gasoline (United Nations Environment Programme 2012). Before the removal, especially in urban areas, children inhaled or ingested lead liberated as a result of the combustion of leaded gasoline, leading to large scale increases in blood lead levels (BLLs) and associated adverse health consequences, including cognitive and behavioral deficits (ATSDR 2007). The average child's blood lead level has decreased substantially: in the 1970s, over 88% of children aged 1-5 years in the United States had BLL ≥10 μg/dL, whereas the most recent data, collected in 2007-2008, show average levels of 1.5 μg/dL, and only 0.9% of children having BLL above 10 μg/dL (US Environmental Protection Agency 2012). A similar trend has also been documented in most European countries (United Nations Environment Programme 2010), as well as in some low- and middle-income countries (LMICs) (Normand et al. 2007).

Yet despite this major landmark accomplishment, significant exposure remains, especially in LMICs (Fewtrell et al. 2004). Lead consumption has significantly increased from 1970 (from 4.7 to approximately 7.1 million tons in 2004), an increase mainly driven by demand for lead batteries (United Nations Environment Programme 2010). Paint is still a major source of lead exposure in childhood, with use in paint globally ongoing to this day, resulting in contaminated dust in homes, which is then either ingested or inhaled. Hazardous waste sites also represent a major source of contamination of water, soil and food, leading to increases in BLL in children

from surrounding communities (United Nations Environment Programme 2012). Other environmental sources include water pipes, solder in canned food, ceramics, traditional remedies (United Nations Environment Programme 2010).

A growing body of literature in recent years has estimated disability-adjusted life year (DALY) losses from exposure to lead in children at the global level (Fewtrell et al. 2004; Murray et al. 2012). While DALYs are highly useful for prioritization of public health interventions in general, for environmental health interventions, cost estimates represent a complementary assessment of burden that can be compared directly with costs of reducing exposure. While costs of childhood lead exposure in the US (Gould 2009; Trasande and Liu 2011) have proven useful for decision-makers there, to date, there have been no estimates of costs related to childhood lead exposure in developing countries.

In this manuscript, we estimate the economic costs attributable to childhood lead exposure in low- and middle-income countries (Table 1).

Methods

General Description

We applied the model first used by the Institute of Medicine (Institute of Medicine, 1981) to estimate the cost of environmentally mediated disease.

While BLLs mainly reflect exposure to lead in the previous few months, and may not reflect the burden of lead in bones (Needleman et al. 1996), it is the most commonly available measure. Increases in BLL among children are associated with decrements in cognitive development, as quantified in intellectual quotient (IQ) loss. We limited our economic analysis to the

neurodevelopmental impact of lead, assessed as decrements in IQ (IQ point loss estimated over three ranges of BLLs: 0.513 IQ point loss per μg/dL for BLL 2-10 μg/dL; 0.19 point loss for BLL 10-20μg/dL; and 0.11 point loss for BLL ≥20 μg/dL, as described by Gould (2009), and chose to focus on the population at risk represented by each 1-year cohort of children <5 years of age, in whom the BLL, when measured longitudinally, is most strongly associated with neurodevelopment at school-age (Hornung et al. 2009).

We did not include mild mental retardation (MMR) in our cost estimates, because cost estimates for MMR are rarely available outside the developed world. Decrements in IQ are associated with reduced lifetime economic productivity, and associations with criminality have also been identified (Needleman et al. 1996; Reyes 2007), but these to date are limited to industrialized countries. Therefore, we did not include costs of increased criminality in our estimates of economic costs to LMICs.

Environmentally Attributable Fraction

We applied an environmentally attributable fraction (EAF) (Smith et al. 1999) of 100%, consistent with scientific literature indicating that only a very small fraction of lead exposure is attributable to natural processes (United Nations Environment Programme, 2010). Accordingly, the attributable cost can be described as follows:

Cost= EAF x BLL x (IQ loss/BLL) x (lost economic productivity/IQ loss) x Population at risk. [1]

In this equation IQ is the intellectual quotient loss for each BLL range of values, as described above, and the population at risk is represented by each 1-year cohort of children <5 years of age. We estimated the number in each cohort as 20% of the total number of 0-4 year old children

reported for each country by the most recent UN estimates (United Nations – World Population Prospect 2010).

Estimation of BLL distributions at the country level

We systematically reviewed the published literature for studies estimating BLLs in LMICs, following the most recent World Bank country classification by income (World Bank 2012a). The published literature was searched using PubMed and terms including "lead" in combination with the name of each country; the initial query was then refined using the "Related Citations" option. We also considered reference lists of relevant articles. We only included studies conducted from 2000 onwards (or for which the recruitment period extended to the year 2000), in pediatric populations (<18 years) or that included a pediatric subpopulation. Studies reporting lead exposure in heavily contaminated areas (hotspots such as areas around metal smelters and battery recycling or gold-ore processing activities, the latter responsible for the recent outbreak of fatal lead poisoning in children in Nigeria (Dooyema et al. 2012) or occupational exposures were excluded, unless they included a control population not residing in the contaminated area. In these latter cases, we only analyzed data from the control population. Country-specific BLL estimates identified based on our review and used in the present analysis are provided along with the sources of these data in Supplemental Material, Table S1.

For the purpose of this analysis, we did not consider urban and rural populations separately, since there is a global trend toward urbanization, and more than half of the world's population now lives in urbanized areas, with urban growth concentrated in Africa and Asia (United Nations 2012).

Estimating BLL from Past Studies

We developed a regression model to relate trends in BLLs over time, and to the timing of the ban in leaded gasoline in each country, and this was done using BLL data retrieved through our literature search. We first examined a simple linear model with respect to trends in BLL over time, and compared our results with a linear plus quadratic model, which resulted in a modest increase of the predictive capability, measured using the R^2. Therefore, our final model included a quadratic term, and is described by the following regression equation:

$$y(t) = \beta_0 - \beta_1 x + \beta_2 x^2 + e \qquad [2]$$

where y is the average BLL at time t (2008), β_0 is the intercept, x is the difference between year of the study and year of leaded gasoline phase-out in the country (United Nations Environment Programme 2012, x^2 is the quadratic term of the difference, and β_1 and β_2 are the coefficients being estimated. The quadratic term is also justified by experience in developed countries, in which the most rapid reductions in childhood blood levels were produced immediately after phase-out and in relationship to more rapid reductions in leaded gasoline use (Fewtrell et al. 2004, US EPA 2003).

Parameters estimate obtained with this model are shown in Table 2, and were used to estimate BLL in each of the countries included in our analysis. Below is a working example for a specific country, Ethiopia, with no recent BLL data available and in which leaded gasoline was phased out in 2004:

- BLL in 2008= [7.33-(0.26*4)+(0.01*16)]=6.45 µg/dL

We used the same model to derive standard deviation (SD) values, but with the inclusion of BLL as one of the coefficients, i.e.:

$$y(t) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 - \beta_3 x_2^2 + e_i \quad [3]$$

where y is the average SD at time t (2008), β_0 is the intercept, x_1 is the average BLL, x_2 is the difference between year of the study and year of leaded gasoline phase-out, x_2^2 is the quadratic term of the difference, and β_1, β_2 and β_3 are the coefficients being estimated. Therefore, for Ethiopia, we estimated the following SD:

-SD in 2008= [0.27+(0.47*6.45)+(0.14*4)-(0.001*16)]= 3.85 µg/dL

For countries with available data, the actual BLL and SD values were used in the regression equation; if the data were collected after 2008, we subtracted 2008 from the year of the study and used the difference. For some of these countries, more than one study reporting blood lead concentrations was available. In this case, we first estimated BLL levels in 2008 using our regression model and then combined these estimates to derive a single, sample-size-weighted, geometric mean, according to a method previously described by Fewtrell et al. (Fewtrell et al. 2003). An example of this is provided in the Supplemental Material.

The same procedure was followed to combine SDs. Once we estimated mean BLL and SD for each country, the percentage of children at or above predefined blood levels intervals (2-10, 11-19, ≥20) was estimated to determine the population ask risk within each exposure interval assuming a log-normal distribution around the estimated mean BLL using the LOGNORMDIST function in Excel 2007 (Redmond, WA: Microsoft, Inc.). For the purpose of this study, we

considered BLL<2µg/dL to present the lowest risk of toxic effects in children, acknowledging that a threshold level does not appear to exist.

Intellectual Quotient loss

Current evidence supports impaired cognitive development associated with lead concentrations below 10µg/dL, and a non-linear, inverse relationship between IQ and BLL has been established (with the greatest rate of IQ loss per unit blood lead <10 µg/dL). Average IQ point loss was derived from an international pooled analysis (Lanphear et al. 2005), over three ranges (0.513 point loss per µg/dL for BLL 2-10 µg/dL; 0.19 point loss for BLL 10-20µg/dL; and 0.11 point loss for BLL ≥20 µg/dL), as described by Gould (2009). Because of the broad range of BLL ≥ 20 µg/dL, we also divided the ≥20 µg/dL group into 20-44, 45-69 and ≥70 µg/dL for purposes of analysis. For each of these BLL ranges, we applied the IQ point loss corresponding to the lowest BLL in the range considered (e.g. for the range 2-10 µg/dL we applied the IQ loss corresponding to 2 µg/dL) IQ loss was calculated for each country using the BLL estimated for that country multiplied by the number of 5 year old children affected each year. IQ losses for each country) were then summed to obtain a total for each subregion in Africa, Asia, and Latin America/Caribbean.

Losses in economic productivity

To estimate lead-attributable costs, the economic model developed by Schwartz et al. (Schwartz et al. 1985) was applied to the calculated prevalence distribution. This model is based on the relationship between lead exposure and dose-related decrements in IQ score, the latter in turn being associated with decreased lifetime earning power.

We estimated lost lifetime economic productivity (LEP) using average IQ point loss per µg/dL BLL, percent lost LEP per IQ point, and total lost LEP. Lost LEP was derived based on a US estimate (Grosse et al. 2002) of decrements in LEP per IQ point loss. For our base-case analysis, we assumed a 2% loss in LEP/IQ point estimate, as previously done (Trasande and Liu 2011), against LEP data from the University of California Institute for Health and Aging, which assume annual growth in productivity of 1% and a 3% discount rate (Max 2007). These data suggest that the value of lifetime expected earnings is $1,413,313 for a 5-year old boy in 2007 and $1,156,157 for a 5-year old girl. These data were then corrected at the country level using gross domestic product (GDP) by converting gross domestic product (GDP) per capita to international dollars using purchasing power parity (PPP) rates (World Bank 2012b).

Sensitivity analyses

Recognizing uncertainty in IQ-lost economic productivity and in trends in BLL, we performed two types of sensitivity analysis to increase the accuracy of our estimates. First, we applied the method used by Fewtrell et al. (Fewtrell et al. 2004) to estimate the exposure distributions in our population of interest. Following this approach, we also accounted for lead-reduction programs that were undertaken after BLLs were surveyed. We used a reduction factor of 7.8% decrease per year (Fewtrell et al. 2004), taking into account the year of the study and the year of leaded gasoline phase-out in each country with available data. For countries with more than one study reporting BLL, we derived a single, sample-size-weighted, geometric mean BLL value and standard deviation (this is described in greater details in our Supplemental Material.) We then obtained a subregional mean BLL by weighting country means by the size of the population under 5 years of age. For countries for which BLL data were not available, we used the corresponding subregional mean and standard deviation to estimate the population distribution of

exposure, assuming a log-normal distribution around the mean BLL for the subregion. Unlike our regression model, this method does not allow for an estimation of BLL at country level for those countries with no recent data available, and uses instead the corresponding subregional BLL mean as a substitute.

Second, recognizing the uncertainty in the relationship between IQ and economic productivity, we used the low- and high-end of our estimate range based on the work of Schwartz et al. (Schwartz 1994) and Salkever et al., (Salkever 1995) who applied a range in percentages of lifetime productivity loss for each point of IQ ranging from 1.76% to 2.37%.

Results

Regression Model for BLL

Model parameter estimates are presented in Table 2. The model predicted a significant inverse relationship between BLL and time, represented by the difference between year of the study and year of leaded gasoline phaseout. Estimates show a significant positive relationship of SD with BLL, with wider dispersion over time.

Base-case analysis

Results are presented for Africa, Asia, and Latin America and the Caribbean following WHO geographic classifications. Using our base-case assumption, we calculated total IQ loss and corresponding LEP lost for each country included in this analysis (Supplemental Material, Table S2), which were summed within subregions and then combined to derive totals for each of the three major regions. Based on our calculations, we estimated reduced cognitive potentials (loss of IQ points) due to preventable childhood lead exposure equal to 98.2 million points in Africa,

283.6 million in Asia, and 24.4 million in Latin America and the Caribbean, which translate into economic losses equal to $134.7, $699.9, and $142.3 billions of international dollars, respectively (Table 3). If we consider these losses in proportion to an estimated world PPP GDP of $81.2 trillion in 2011 (World Bank 2011), these amount to 1.20% of the global GDP.

In Africa the highest estimated total losses in economic productivity are in Northern and Western Africa (Table 3). Egypt and South Africa are the countries with the largest costs, with estimated losses equal to $17.8 and $17.7 billion, respectively (Supplemental Material, Table S2). Of note, these economic losses correspond to 4.03% of African PPP GDP (Table 3). In Asia, Eastern and Southern Asia account for most of the lost economic productivity in the continent. China, with estimated losses equal to $227.1 billion, and India, with losses equal to $236.1 billion, shoulder the largest proportion of these costs. South America accounts for most of the economic losses in Latin America and the Caribbean: Brazil bears the largest burden, with losses estimated at $33.1 billion.

Sensitivity Analysis

Our sensitivity analyses suggest a range of economic losses in the range of $118.5-$160.3 billion in Africa, $78.1-$169.3 in Latin America and the Caribbean, and $532.0-$832.9 in Asia (Table 3). Globally, our sensitivity analysis produces a range from $728.6-$1,162.5 (0.90-1.43% of global GDP).

Discussion

The principal finding of our analysis is that, despite a decline in blood lead concentration worldwide, lead exposure still represents a major contributor to children intellectual disability in

many LMICs. This, in turn, translates into significant earning losses over a lifetime, which we estimated at 1.20% of the world GDP. Economic losses due to lead exposures in children will continue unless measures to prevent lead exposure are implemented in all countries.

For our estimates, we chose to focus on loss of IQ and its impact on earning potential, which has been the subject of several analyses (Grosse et al. 2002). In general, the impact of IQ on earnings can be considered the result of direct effects, i.e. lower cognitive capacities, and indirect effects due to diminished educational achievements and reduced labor force participation. From a population perspective, even a small loss in IQ score has important repercussions on losses on potential earnings. Indeed, while an apparently small change like a 1-point decrease in IQ score might not be significant at the individual level, at the population level this will result in a shift in the distribution of IQ and an increase in the number of individuals who are below the levels used to define those below the normal range (Bellinger 2004).

Estimating and aggregating future earnings foregone, or lost LEP., provide a sense of the potential economic benefits of preventing childhood lead exposure that persists in LMICs. We consider our estimates to be conservative, since we did not take into account consequences of lead exposure later in life, such as cardiovascular consequences; furthermore, in our analysis, we excluded data regarding blood lead concentration near hotspots, probably underestimating the burden of intellectual disability and therefore the associated economic losses. We did not include other societal costs that may result from childhood lead exposure, such as violence and antisocial behaviors. Previous work suggests that cardiovascular disease, violence and other related costs may be equivalent to or greater than the lost economic productivity costs described here (Gould 2009; Nevin et al. 2008).

Following the phase-out of leaded gasoline in most countries, mean BLL have significantly declined around the world (United Nations Environment Programme 2012), with an estimated global benefit of US $2.45 trillion/year, 4% of world GDP in 2008 (Tsai and Hatfield 2011). However, it is now increasingly recognized that lead affects cognitive and behavioral development at levels lower than previously thought (Grandjean 2010), and so full benefits of preventing childhood lead exposure have yet to be realized. In many areas of the world included in our analysis, blood lead concentrations are still significantly elevated, well above the new levels currently established by the US Centers for Disease Control and Prevention (Centers for Disease Control and Prevention 2012). While the disease burden attributable to lead has been estimated at a global level (Fewtrell et al. 2004), economic evaluations to estimate the costs of this burden, especially lost LEP due to childhood lead exposure, have been conducted mainly in the US and in Europe (Gould 2009; Pichery et al. 2011), but not in most developing countries, which currently stand to lose the most from this hazardous chemical exposure. Perhaps in contrast to 30 years ago, when lead poisoning was best documented in the industrialized world, a disproportionate burden of lead-associated disability and economic cost is now borne by developing countries. For comparison, US and Europe lead-attributable economic costs have been estimated at $50.9 and $55 billion, respectively (Trasande and Liu 2011), compared with $977 billion in LMICs, suggesting that this is where most of the losses are nowadays.

While we apply data from an international pooled analysis to assess BLL-IQ point relationships (Lanphear et al. 2005), this relationship is based on the results of studies done largely in high-income countries, assuming that the relationship is similar among children from LMICs. This might be true, but given the different comorbidities among children in high-income and LMIC countries, we cannot be certain that such relationship apply in these countries as well.

We applied US data relating IQ to percent economic productivity to estimate lost productivity across LMIC countries. As Salkever points out (1995), technological change associated with economic growth increases the impact of IQ on productivity. In 1995, the US had already achieved dramatic technological growth. If LMIC technological growth is, greater than in the US then the impact of IQ (and lead exposure) on productivity in LMICs is greater than we estimated, and we are therefore likely to have underestimated the lost economic productivity due to childhood lead poisoning. We also appreciate that there is significant variability in technological growth rates across the LMICs, and so there is potential for great uncertainty introduced by using an input from a single, industrialized nation.

We also extrapolated individual-level lifetime economic productivity from US data, applying a PPP GDP correction factor. Given the much higher rates of growth in GDP per capita in some LMICs like China and India and several Southeast Asian countries, annual productivity gains are almost certainly higher than in the U.S. and so we have likely underestimated the losses for these countries. Extrapolation from US data, however, once again produces uncertainty in the estimates produced for childhood lead poisoning costs at the country level, given that GDP growth varies so widely among LMICs, leading to overestimation for some countries as well as underestimation for others.

We also assume that each country has a similar rate of decline in BLL in relationship to the year in which leaded gasoline use was phased out. Another limitation on our analysis is that, for some regions of the world, very little information was available, highlighting the need to collect more data on blood lead concentrations. However, using our regression model to predict BLL in countries in which data were not available represented a significant advantage over the method

used by Fewtrell et al., (2004) allowing us to estimate BLL in regions of the world (Middle Africa, Central Asia, and the Caribbean) for which recent or complete data were not available.

We acknowledge that the literature examining the effects of multiple chemical exposures and their potential synergistic interactions is still not well developed, and any quantification of the economic consequences of lead exposure is inherently limited by the available data. Measurements of BLL were performed in different laboratories, and not all of them with adequate accreditation or standard reference material, significantly increasing variability and the possibility of measurement errors.

Although a comprehensive quantification of the potential economic benefits of preventing lead exposures is still at an early stage, there is evidence suggesting that, in the US, the net benefits of lead hazard control total $181-$269 billion, whereas the estimated costs range from $1.2 to $11.0 billion (Gould 2009). Most payers only consider the upfront expenses required for lead hazard control, because the majority of the benefits will occur in the future, and therefore there is no immediate return on the investment. However, the long-term returns are great: a more recent analysis conducted in the US suggests that the estimated benefits deriving from treatment of residential lead-based paint hazards are two to twenty times higher than the estimated costs of remediation (Jones 2012). In one of the few studies conducted in the developing world, Ogunseitan et al. estimated that lead exposure accounts for 7-25% of the disease burden among Nigerian children, and a 50% decrease in childhood BLL could save $1 billion per year. In addition, a lead abatement program lowering national BLL to 1 µg/dL by 2020 would realize a saving in the range of $2.7-8.0 billion (Ogunseitan and Smith 2007).

Persistence of lead in the environment, in addition to uncontrolled release, will contribute to population burden for a long time to come, if interventions are not initiated now. Since there is no "safe" blood lead threshold for children and medical treatments are of limited value, the only way to avoid the large economic costs related to lead exposure is primary prevention, also because the cost of medical treatment, if provided, might be higher than interventions aimed at preventing exposure (at least in some countries) and does not reverse the damage (Grosse et al. 2002).

Conclusions

Our estimates suggest that lost LEP associated with childhood lead exposure in LMICs currently amounts to $977 billion annually. These findings are consistent with other studies and confirm a large economic burden that could be avoided if policy interventions to prevent lead exposures are implemented. Any costs of lead control interventions are at least partly offset (if not entirely offset in some circumstances) by the health and economic benefits deriving from reducing exposure, which is a strong argument to continue to investing in lead hazard control. Non-governmental and governmental funding entities should consider the cost of global lead poisoning as an area of ongoing concern: without adequate preventive measures, the cost of inaction is represented by substantial economic losses and health consequences for society as a whole for generations to come.

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Table 1. Countries included in the study by region

WHO region	
Africa	
Eastern Africa[a]	Burundi, Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, , Somalia, Uganda, Tanzania, Zambia, Zimbabwe
Southern Africa	Botswana, Lesotho, Namibia, South Africa, Swaziland
Western Africa	Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo
Middle Africa	Angola, Cameroon, Central African Republic, Chad, Congo, Democratic Republic of Congo, Sao Tome and Principe
Northern Africa	Algeria, Egypt, Libya, Morocco, Sudan, Tunisia
Asia	
Eastern Asia[b]	Democratic People's Republic of China, Mongolia
Southern Asia	Afghanistan, Bangladesh, Bhutan, India, Iran, Nepal, Pakistan, Sri Lanka
Central Asia	Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan
South Eastern Asia	Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand, Timor Leste, Vietnam
Western Asia[c]	Armenia, Azerbaijan, Georgia, Iraq, Jordan, Lebanon, Syria, Turkey, Yemen
Latin America & the Caribbean	
Central America	Belize, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama
South America	Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela
Caribbean[d]	Dominican Republic, Grenada, Haiti, Jamaica, Saint Lucia, Saint Vincent and the Grenadines

[a, b, c, d] Countries not included in the economic analysis because either no GDP per capita data or no data on population under 5 years were available: Seychelles, North Korea, Occupied Palestinian Territory, Antigua and Barbuda, Cuba, Dominica, Saint Kitts and Nevis.

Oceania is not included, since the vast majority of the population reside in Australia and New Zeland, both high-income countries

Table 2. Model parameter estimates (mean and 95% confidence interval) for blood lead levels and related standard deviations predicted for each country in 2008

Model parameter	Results	P-values
BLL		
Intercept (β_0), BLL[a] (µg/dL)	7.33 (6.18, 8.48)	<0.001
Time coefficient (x)	-0.26 (-0.43, -0.09)	0.003
Quadratic time coefficient (x^2)	0.01 (-0.01, 0.04)	0.31
R^2	0.12	
SD		
Intercept (β_0), SD[a] (µg/dL)	0.27 (-0.86, 1.41)	0.63
BLL coefficient (x_1)	0.47 (0.33, 0.60)	<0.001
Time coefficient (x_2)	0.14 (0.05, 0.24)	0.005
Quadratic time coefficient (x_2^2)	-0.001 (-0.023, 0.01)	0.89
R^2	0.54	

[a] For countries were BLL and SD data were available the country's actual value was used

Table 3. Lifetime economic productivity (LEP) lost in Africa, Asia, Latin America and the Caribbean for each 1-year cohort of children under 5 years of age

WHO Region	WHO Subregion	Presumed IQ loss (millions of points)	Lost LEP per IQ point (base case)	Population in each 1-year cohort of under 5yrs (million, except Caribbean)	Lost LEP per 1-year cohort of under 5yrs, billions of dollars (range, including both sensitivity analyses)
Africa	Northern Africa	15.3	$26,400	4.7	$48.4 ($41.1- $57.6)
Africa	Eastern Africa	36.0	$16,500	10.6	$23.1 ($20.4- $29.1)
Africa	Western Africa	28.9	$13,100	10.2	$27.9 ($24.6-$51.6)
Africa	Middle Africa[a]	14.7	$17,600	4.4	$14.9($13.1- $17.8)
Africa	Southern Africa	3.8	$20,500	1.2	$20.3 ($17.8- $24.0)
Africa	**Total**	**98.6**	**$94,100**	**31.1**	**$134.7 ($118.5-$160.3) or 4.03% of GDP PPP (3.54%-4.80%)**
Asia	Eastern Asia	55.1	$6,300	16.4	$227.7 ($193.9-$270.9)
Asia	Southern Asia	176.3	$17,600	36.3	$325.1 ($238.7-$386.9)
Asia	South- Eastern Asia	36.4	$23,100	10.7	$90.2 ($76.8-$107.4)
Asia	Western Asia	10.9	$36,500	4.1	$42.2 ($22.5-$50.2)
Asia	Central Asia[b]	4.9	$15,200	1.3	$14.7 ($12.9-$17.5)
Asia	**Total**	**283.6**	**$98,600**	**68.8**	**$699.9 ($532.0 -$832.9) or 1.88% of GDP PPP (1.43%-2.24%)**
Latin America & the Caribbean	Central America	7.1	$35,200	3.3	$42.0 ($18.2-$50.0)
Latin America & the Caribbean	South America	15.9	$64,000	6.8	$96.2 ($59.9- $114.5)
Latin America & the Caribbean	Caribbean[c]	1.5	$54,800	514,000	$4.1 ($3.6- $4.9)
Latin America & the Caribbean	**Total**	**24.5**	**$154,000**	**10.6**	**$142.3 ($78.1-$169.3) or 2.04% of GDP PPP (1.12%-2.42%)**

[a,b,c] Economic losses for all countries in Middle Africa, Central Asia and for the Caribbean could only be calculated using our regression model to estimate country BLL, since no recent data or complete were available for which to use the method described by Fewtrell et al. (2004)