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ARTICLE

Lead-attributable productivity losses in low- and middle-income countries

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Abstract
This study estimates productivity losses resulting from intellectual decrement due to paediatric lead exposure in low- and middle-income countries (LMICs). The published literature on blood lead levels in LMICs was reviewed and summarised. Intelligence Quotient decrement and consequent productivity losses were calculated for a one-year cohort of 5-year-old children in each country. We calculated the present value of lifetime earnings as the discounted average earning potential for workers in a specific economy. Blood lead level (BLL) data for children were available for 39 countries and could be interpolated for additional 82 countries, resulting in 121 countries in the final analysis. Total lead-attributable productivity losses in LMICs ranged from USD 305 billion in our high discount scenario to USD 499 billion in our low discount scenario for each one-year cohort of 5-year-old children (2019 USD). As a share of GDP, these costs ranged from 0.7 to 4.2% by region, depending on discount scenario used. Total economic impacts were generally consistent with previous estimates and further validate those efforts with a substantially expanded dataset. Differences in the findings resulted primarily from the use of a more conservative dose–response model in the present study. Improved reporting of BLLs is essential and could be facilitated through a centralised registry of study results.

Keywords: lead exposure; Pb; developing countries; low- and middle-income countries (LMICs); costs

1. Introduction

Countries with widespread blood lead level (BLL) testing have documented that average BLLs declined precipitously following the elimination of leaded gasoline, with ranges reported from 30–48% within 5 years of phaseouts (Fewtrell *et al.*, 2003). Nonetheless lead remains common in the environment and many children are exposed at levels known to cause adverse effects.

Lead is a potent neurotoxicant that adversely impacts most of the body's enzyme systems (Flora *et al.*, 2012). There is no known safe BLL for children, who are particularly vulnerable. Children seldom exhibit symptoms at the time of exposure and the many long-term impacts, including decreased Intelligence Quotient (IQ) and behavioural challenges limiting academic and professional success, cannot be recognised until later in life (Breit *et al.*, 2021). The World Health Organization (WHO) has estimated that lead exposure accounts for 30% of the global burden of idiopathic developmental intellectual disability (WHO, 2021).

The economic cost of paediatric lead exposure can be conservatively quantified as the effect of reduced cognitive capacity on lifetime economic productivity (Grosse *et al.*, 2002; Landrigan *et al.*, 2017). Lead exposure impairs the development of grey matter in the brain and reduces IQ. Effect size estimates vary widely; loss of a single IQ point has been quantified as a 0.5–2.5% reduction in lifetime earning capacity (Grosse and Zhou, 2021). Lead's impact is proportionately greater at lower levels of exposure (Crump *et al.*, 2013; Lanphear *et al.*, 2005; Budtz-Jørgensen *et al.*, 2013). For example, BLLs of 5 and 15 μg/dL have been associated with decrements of 2.9 and 5.5 IQ points, respectively (Budtz-Jørgensen *et al.*, 2013). However, deficits continue at higher levels of exposure, with BLLs ≥ 65 μg/dL being associated with major intellectual disability, seizure disorders and death (ATSDR, 2020).

Two studies since 2010 have calculated productivity losses attributable to paediatric lead exposure in low- and middle-income countries (LMICs). First, Attina and Trasande (2013) evaluated a one-year cohort of < 5-year-old children, finding total lifetime losses of international $ 977 billion (2011 Purchasing Power Parity [PPP]) (Attina and Trasande, 2013). Ten years later, relying on a larger BLL dataset, Larsen and Sánchez-Triana (2023) found substantially higher losses, totalling approximately international $ 1.61 trillion (2019 PPP) (Larsen and Sánchez-Triana, 2023). Here we develop a third valuation of lead-attributable productivity losses in LMICs. We utilise BLL data from a substantially larger systematic review than previous studies, comprised of 388 unique publications. For context, the datasets used by preceding efforts comprised fewer than 100 studies. Further, we interpolate BLL data for countries where blood lead information was unavailable, providing a larger dataset of country-specific BLLs. We then provide a comparison of our results with preceding studies to demonstrate the significance of major assumptions and data gaps.

2. Methods

The published literature on BLLs in LMICs was reviewed and summarised. IQ decrement and consequent productivity losses were then calculated for a one-year cohort of 5-year-old children in each evaluated country.

2.1 Estimation of national level BLLs

We evaluated all 136 LMICs of the World Bank's June 2020 list of economies (World Bank, 2020). BLL estimates for each country were taken from a recent systematic review that presents background BLL levels for 34 countries and hotspot BLL levels for 23 countries (Ericson *et al.*, 2021). Values for the remaining countries were identified through a literature review or imputed if no studies were identified.

A 2022 PubMed search was conducted using the search terms '[country name]', 'blood' and 'lead' (all fields, MeSH terms) for studies published after the country's leaded petrol phaseout date. Results were further filtered by species (Human) and age (Child: birth–18 years). Only those countries missing estimates in a recent systematic review were included in the search (Ericson *et al.*, 2021).

Results returned by PubMed were screened for relevance through a title and abstract review. The full text of relevant studies was then assessed against five inclusion criteria: contained BLLs from children < 18 years residing in the target country; comprised of ≥ 30 participants; presented BLL data (ie. central tendency) derived from venous, capillary, or umbilical cord samples of whole blood; data collected at least 12 months after the leaded petrol phaseout; and contained data that had not been reported elsewhere (ie. excluding systematic reviews or subsequent studies of the same cohort). Studies meeting these criteria were assessed for bias and quality using a bespoke tool developed for this study and available in the supplementary materials.

BLL data were extracted from studies meeting the inclusion criteria and passing the bias assessment. Available measures of central tendency (eg. mean, median) and dispersion (eg. SD, 95% CI) were extracted for children < 18 years of age. Other descriptive statistics and the method of laboratory analysis (eg. ICP-MS, AAS) were also extracted if available. Subgroups were coded as either 'background' or 'elevated exposure' the latter comprised of populations identified as having lead exposure uncharacteristic of the general population (eg. proximity to a hotspot or use of leaded cosmetics). The subgroup 'background' was intended to capture general population exposure and included population assessments, control groups in case-control studies, and similar efforts. Results were taken at face value and were not reinterpreted.

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In countries with more than one study, the mean of the log-transformed sample-weighted values was taken for each, following previous work (Fewtrell *et al*., 2003; Attina and Trasande, 2013; Ericson *et al*., 2021). Background and elevated exposure subgroups were analysed separately. Missing mean and standard deviation values were imputed using indicators of central tendency and dispersion as described elsewhere (Ericson *et al*., 2021). Two countries, China and the Republic of Georgia, had recent population-based studies of BLLs that met our inclusion criteria (UNICEF, 2019; Li *et al*., 2020). The results from these studies only were used and were not pooled with those from other efforts. Finally, the most recent available citation list from the Institute for Health Metrics and Evaluation's (IHME) 2017 Global Burden of Disease was reviewed to identify any studies that may have not been identified in the preceding steps (IHME, 2018). All pooled BLLs, regardless of the year of data collection or the age of the children, were taken as reflecting the cumulative lifetime exposure to a cohort of 5-year-old children 2019.

If a country's background BLLs were not identified, we spatially interpolated them based on known values using Triangulated Irregular Network (TIN) interpolation.

2.2 Estimation of hotspot exposure

BLLs for elevated exposure subgroups for each country were also identified based on the five inclusion criteria. The number of children with elevated exposures was then conservatively approximated as 0.1% of a country's population based on a 2016 study of informal lead recycling in LMICs (Ericson *et al*., 2016).

2.3 Economic cost methods

The effect of lead exposure on IQ was calculated using pooled BLLs indexed against associated piecewise linear IQ decrement previously estimated (Budtz-Jørgensen *et al*., 2013). Here, IQ decrement is proportionally greater at lower BLLs, below a breakpoint of 7.5 ug/dL (see Figure 1 in the supplementary materials). Thus, in the present study IQ decrement was calculated for different BLL intervals, beginning with 0.2–1 ug/dL. Intervals then increased by units of 1 ug/dL until the 25 ug/dL, with the final interval capturing BLLs greater than 25 ug/dL. These values were then summed to arrive at total IQ decrement and associated costs for a given country.

The loss of a single IQ point has been quantified as a 0.5–2.5% reduction in lifetime earnings. We used the recently conservatively estimated IQ value as 1.4% of the present value of lifetime earnings for both market and nonmarket labour (Grosse and Zhou, 2021). The present value of lifetime earnings is the discounted average earnings for workers in a specific economy over the course of their lives. It is calculated as labour's share of GDP divided by the number of workers and adjusted for both the rate of growth in output per worker and a social discount rate (Landrigan *et al*., 2017; Krupnick and Cropper, 2019). We assume that the social discount rate will exceed growth per worker by 1.5% (low) or 3% (high). Thus, it is calculated as follows: $[1/(1+d)]$, where $d = 0.015$ or 0.03 (Landrigan *et al*., 2017). We further include the value of nonmarket labour at 25% of market labour following previous work and based on US Bureau of Economic Analysis estimates (US Bureau of Economic Analysis, 2022; Krupnick and Cropper, 2019). Lifetime earnings are then weighted by the probability that a worker will survive from one year to the next using the Global Health Observatory survival rates (WHO, 2022). Lifetime earnings are calculated for a one-year cohort of 5-year-old children. To control for the impact of the COVID-19 pandemic, all economic data are from the year 2019. All results are presented in 2019 USD unless stated otherwise. Further detail, including underlying equations and sources, is provided in the supplementary materials.

2.4 Data analysis

Data were aggregated and analysed in Microsoft Excel and Stata. IQ decrement and associated productivity losses were estimated in Microsoft Excel. Spatial analysis and interpolation were conducted in QGIS (QGIS Development Team, 2024; Microsoft Corporation, 2022; StataCorp. LP, 2017).

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2.5 Sensitivity analysis

Our sensitivity analysis evaluated the influence of the percent difference in market productivity attributable to a single IQ point, using the estimates described above and varying the values to 1 or 2%. As part of our sensitivity analysis, interpolation was conducted with Inverse Distance Weighting (IDW) which more heavily weights known proximate points than distant points. The IDW interpolation was conducted with 6 different weights (p coefficients).

3. Results

3.1 Literature Review

Our PubMed search was conducted for 101 countries and returned 676 titles. Of these 54 titles were considered relevant and reviewed against the inclusion criteria and are reported in the supplementary materials. Thirty-nine studies were excluded at this stage, leaving 15 studies available for inclusion. A review of the IHME citation list returned one additional study which passed our bias assessment. Thus the literature review resulted in a total of 16 additional titles (See Figure 1). Data on background groups were available for six countries ($n = 12$ studies), while data on elevated exposures were available for one ($n = 4$ studies). These 16 studies were then joined with previous work as well as with recent studies from China and Georgia for the analysis, resulting in 388 unique publications (Ericson *et al.*, 2021; UNICEF, 2019; Li *et al.*, 2020).

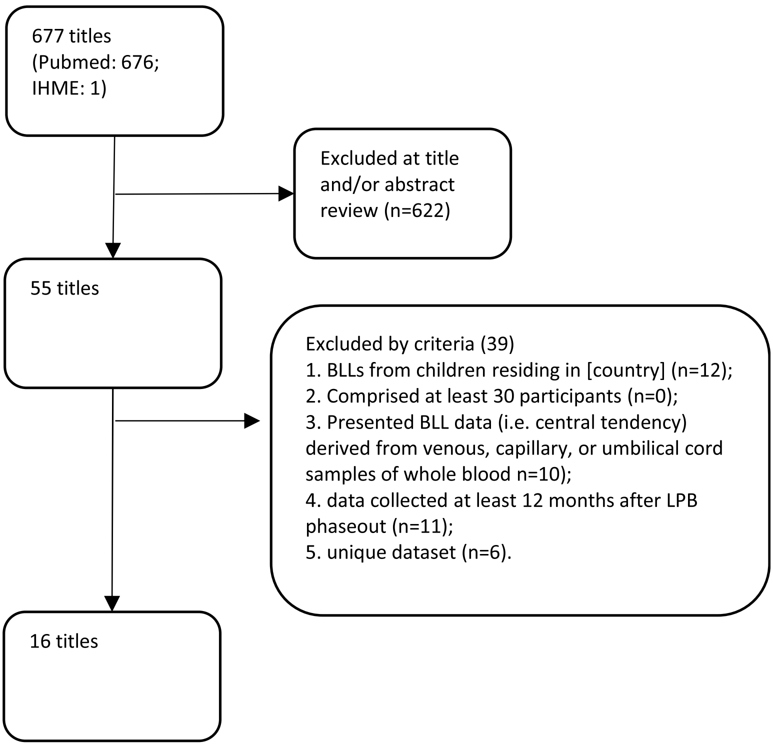

Figure 1. Literature review flowchart.

3.2 Estimation of national level BLLs

Background BLL data were pooled for a total of 39 countries, combining previous data for 33 countries with data from 6 countries extracted as part of the literature review. Romania,

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included in previous work, was no longer classified by the World Bank as an LMIC in 2019 and was therefore excluded. Argentina, excluded from previous work, became classified as an LMIC in 2019 and was therefore included.

Data on sub-populations with elevated exposures were available in 25 countries. BLLs in the subgroups were highly variable ranging from 1.76 μg/dL to 58.5 μg/dL for Bolivia and Nigeria, respectively. Of these 19 (76%) had mean BLLs for the elevated exposure subgroup that exceeded 5 ug/dL; 40% had means exceeding 10 μg/dL.

3.3 National IQ and productivity losses

National BLL estimates could be calculated using existing studies for 39 countries and were interpolated for an additional 82 countries using the TIN approach, with the remaining countries being too distally located from known values to be approximated. Total lead-attributable IQ losses were calculated as 403 million points. Consequent productivity losses in LMICs ranged from USD 305 billion in our high discount scenario to 499 billion in our low discount scenario for each one-year cohort of 5-year-old children (2019 USD). Productivity losses as a share of GDP were lowest in East Asia and the Pacific (range: 0.7–1.1%) and highest in Sub-Saharan Africa (range: 2.6–4.2%). Conversely, productivity losses in East Asia and the Pacific were far larger in absolute terms than other regions, accounting for nearly 38% of the LMIC total.

Table 1 presents productivity loss estimates for the 121 countries for which BLL data were reported or could be interpolated. The results are organised by World Bank region and include ranges in country-level estimates of BLL, IQ decrement, and associated costs. Full country-level results are provided in the supplementary materials.

3.4 Hotspot IQ and productivity losses

National productivity losses attributable to hotspots ranged from USD 117,000 for Armenia to nearly USD 300 million for China. Table 2 presents productivity loss estimates for the 25 countries for which BLL data were reported. Our method for quantifying the IQ decrement associated with a given BLL was capped at 25 μg/dL (IQ decrement of 7.03 points). Pooled BLLs in three countries exceeded this level: Ecuador, Egypt and Nigeria.

3.5 Results of sensitivity analysis

Adjusting the value of an IQ point from 1.4 to 2% of lifetime earnings increased global productivity losses from USD 305–499 billion to USD 436–712 billion. Lowering this value to 1% reduced total losses to USD 218–356 billion. Using IDW interpolation resulted in comparable though less well-fitting BLLs than TIN when compared to the original dataset (see supplementary materials).

4. Discussion

This study calculated productivity losses of USD 305 billion to USD 499 billion in LMICs for each one-year cohort of 5-year-old children (2019 USD), depending on the discount scenario used. In terms of their share of GDP, these losses range from 0.7 to 1.1% in East Asia and the Pacific to 2.6–4.2% in Sub-Saharan Africa. Results in East Asia and the Pacific were driven largely by the values for one country, China, which comprises roughly 50% of IQ points lost and 76% of absolute productivity losses in the region. China is only one of two countries in the study with BLLs based on representative data, thus eliminating a major limitation of the analysis and underlining the importance of improved data collection.

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Table 1. Productivity loss estimates for the 121 countries, by World Bank Region, for which BLL data were reported or could be interpolated. All values in 2019 USD

Region	Population of one year cohort of 5-year-olds (million)	BLL range (ug/dL)	Population weighted mean BLL (ug/dL)	Total IQ points lost (million)	IQ point value range (high discount; USD)	IQ point value range (low discount; USD)	Productivity losses (high discount; billion USD)	Productivity losses (low discount; billion USD)	Productivity losses as % of GDP
Latin America & Caribbean	9.4	2.65–6	3.27	24.4	367–3,214	591–5,284	44.6	72.8	0.9–1.5
Sub-Saharan Africa	33.2	1.66–8.7	5.73	113.6	70–2,718	115–4,432	46.3	76.1	2.6–4.2
Europe & Central Asia	6	2.3–8.48	4.93	19.5	303–2,283	499–3,794	28.7	47	0.9–1.5
South Asia	35	5.11–9.27	6.2	133	207–3,029	332–4,948	45.9	75.3	1.3–2.1
Middle East & North Africa	9.2	1.1–9.3	5.44	30.7	362–4,499	588–7,061	23.8	38.7	1.8–2.9
East Asia & Pacific	29.6	3.06–6.9	3.97	81.7	239–2,345	387–3,819	115.6	188.9	0.7–1.1
Total	122.3			402.9			305	498.8	

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Table 2. Productivity loss estimates attributable to hotspot exposures in the 25 countries for which BLL data were reported (low estimate assuming 0.1% of the children exposed). All values in 2019 USD

Country	Population of one year cohort of 5-year-olds)	BLL	Total IQ points lost	Productivity losses (high discount)	Productivity losses (low discount)
Armenia	43	6	162	117,841	195,000
Bangladesh	2,927	3.7	9,240	3,254,037	5,329,266
Bolivia (Plurinational State of)	252	1.76	588	450,501	740,607
Brazil	2,936	3.61	8,742	15,469,185	25,008,029
China	18,255	9.45	78,414	167,179,780	272,753,954
Colombia	734	4.7	2,316	3,225,235	5,289,631
Ecuador	310	32.25	1,552	2,473,750	4,081,275
Egypt (Arab Republic of)	2,621	40.84	15,117	8,720,876	14,337,023
India	24,143	10.04	105,374	36,692,011	60,415,112
Indonesia	4,743	9	19,456	8,315,299	13,632,690
Iran (Islamic Republic of)	1,532	6.49	5,947	3,099,197	5,055,750
Kosovo	26	2.58	53	70,017	114,574
Malaysia	525	3.75	1,464	3,432,627	5,588,638
Mexico	2,164	5.15	7,715	18,887,619	30,822,463
Morocco	689	7.1	2,773	2,008,368	3,278,753
Nigeria	6,206	58.53	33,178	16,342,620	27,273,989
Pakistan	5,805	14.9	28,823	9,800,507	15,900,884
Peru	583	8.56	2,490	3,209,676	5,260,073
Senegal	478	14.97	2,250	718,841	1,186,235
Serbia	71	17.57	353	757,859	1,257,173
South Africa	1,154	7.37	4,743	5,521,630	8,991,512
Thailand	774	9.8	3,438	6,310,108	10,418,035
Turkey	1,374	12.73	6,881	13,381,299	21,653,853
Vietnam	1,514	24.94	7,529	5,001,288	8,157,329
Zambia	564	24.08	2,635	1,082,281	1,769,967

These estimates are conservative. The spectrum of health effects from lead exposure ranges from subtle to severe, and exposure is associated with toxicity to every organ system. Societal economic costs are typically attributed to adverse outcomes that result in decreased productivity or increased need for healthcare. Adult lead exposure has well-documented effects on the cardiovascular system, increasing both systolic and diastolic blood pressure (ATSDR, 2020). Associated increases in morbidity and mortality costs are substantial and have been calculated elsewhere (Lamas *et al.*, 2021; Larsen and Sánchez-Triana, 2023). The global cost of heart failure in a single year (2012) has been estimated as USD 108 billion, with 60% being borne by healthcare systems and 40% associated with indirect costs, such as lost productivity and unpaid medical bills (Cook *et al.*, 2014). The attributable fractions of low-level lead exposure for cardiovascular disease mortality and ischemic heart disease have been calculated as high as 28.7% and 38.4%, respectively (Lanphear *et al.*, 2018). Thus by estimating only those productivity costs associated with paediatric lead exposure, the present study vastly underestimates lead's overall impact.

For hotspots, children's BLLs can reach levels exceeding 100 µg/dL (Bose-O'Reilly *et al.*, 2017; Dooyema *et al.*, 2012). Some impacts of very high blood lead levels on children are well understood including severe intellectual disability, seizure disorders, blindness and death. However, most studies base their IQ decrement estimates on cohorts of children in affluent countries with much lower exposure levels. Thus in the present study, IQ decrement could be estimated for BLLs up to 25 µg/dL only; all BLLs exceeding this level were assumed to have an equivalent IQ loss of 7.08 points. The neurological impacts of lead exposure do not stop at 25 µg/dL and the literature is replete with case studies and reports of the drastic impact of frank childhood lead poisoning. Further, there is evidence that attributable IQ decrement continues beyond childhood into adolescence and adulthood, implicating costs not captured here (Reuben *et al.*, 2017).

A key reason that childhood lead exposure does not receive attention commensurate with its impact is lack of comprehensive and publicly available information. The existing studies provide a compelling argument that supports taking a closer look at blood and environmental lead levels in most countries. Biomonitoring and population-based surveys generalisable to an entire country can provide estimates of national lead exposure. Biomonitoring also provides measures against which population-wide BLL reduction can be assessed. Systematic small-area studies in communities or subpopulations known or suspected to be at higher risk for lead exposure provide estimates that inform specific remediation strategies to these communities and can also be compared to the general population (Egan *et al.*, 2022).

There is a great need to strengthen methods for conducting and reporting data on lead in children's blood and environment, as reflected through the small number of studies that could be included here. It is critical that a key set of demographic, geographic, environmental, and BLL reporting standards be developed to improve data quality.

The routine reporting of data, including that from the peer-reviewed literature, to a central repository could support efforts to understand the nature and extent of global lead exposure. This evidence base could further be used in the identification and remediation of lead sources and monitoring and evaluating efforts to eliminate lead exposure worldwide.

4.1 Comparison with existing studies

We benchmarked our main results against Attina and Trasande (2013) and Larsen and Sánchez-Triana (2023). Only Larsen and Sánchez-Triana (2023) report on the results of their BLL calculations, which they do by World Bank region. Here the results of the two studies are similar, with all regional population-weighted BLL estimates being in the range of 0–0.63 µg/dL of each other. An exception was Europe and Central Asia where the present study found a population-weighted BLL 2.63 µg/dL greater than Larsen and Sánchez-Triana (2023). We attribute the

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variation to the small number of studies in the region and thus increased relative influence of any one study's results on the regional estimate.

With regard to IQ decrement, Attina and Trasande (2013) found a total loss of 407 million IQ points in LMICs. This study identified a nearly equivalent loss of 403 million IQ points. By contrast, Larsen and Sánchez-Triana (2023) find a substantially larger loss of 729 million IQ points. More detailed comparisons between the three studies were not possible given differences in reporting. Most significantly Larsen and Sánchez-Triana (2023) report the majority of their findings at the global or regional level only, without disaggregating by country income level.

Both Attina and Trasande (2013) and Larsen and Sánchez-Triana (2023) assessed the value of an IQ point as 2% of lifetime earnings. Attina and Trasande (2013) also report results in international dollars (ie. at PPP). This is distinct from the present study, which utilises a value of 1.4% of lifetime earnings and presents results in 2019 USD. International dollars are adjusted to take into account the relative purchasing power of a US dollar in a given economy. Thus in international dollar terms, the value of one dollar in the United States is reflected as $ 1, while the same dollar would be valued at $ 2.34 in Kenya or $ 0.97 in Japan (2019 international dollars). For the purpose of comparison, we adjusted our assessment of lifetime earnings upward to 2% and converted our results to 2019 international dollars. We also converted the Attina and Trasande (2011) results to 2019 international dollars. Larsen and Sánchez-Triana (2023) report their findings in both 2019 international dollars and USD, however, they do not fully disaggregate LMICs from their global results. We thus approximate total losses based on information provided.

Following these conversions, the main results of the three studies are similar with the present study finding international $ 1–1.7 trillion in losses compared to international $ 1.3 trillion (0.9–1.58) found by Attina and Trasande (2013) and international $ 1.61 trillion (736–2,415) found by Larsen and Sánchez-Triana (2023) (2019 International dollars). We attribute the higher values of the Larsen and Sánchez-Triana (2023) to their use of a more severe dose–response model to calculate IQ decrement than those employed in the other two studies. This observation was also made by Larsen and Sánchez-Triana (2023).

4.2 Limitations

Our results are limited by multiple factors. The most substantial among these is the dearth of data available on BLLs in LMICs. Nationally representative studies were available in only two of the 136 LMICs (China and Georgia). Background BLL data on children could be identified in 39 countries only. With the exception of the two countries noted above, these data were not initially collected for the purpose of inferring a nationally representative value. BLLs for all other countries ($n = 82$) were interpolated based on data reported in proximal countries. This necessarily introduces error into our estimates as in reality a large number of factors influence actual BLL concentrations. IHME (2017) attempted to improve on simple geographic interpolation with the use of predictive covariates, relating primarily to the effects of leaded petrol and urbanicity. It is unclear how and if the inclusion of these covariates improves on the methods used here. Lead exposure in LMICs is attributable to multiple and disparate sources, including adulterated spices and ceramic glazes that are unrelated to urbanicity or leaded petrol. Attina and Trasande (2013) similarly employ a simple geographic interpolation. Given the level of uncertainly in the interpolated country-specific estimates, we provide only regional summaries in our main results. To facilitate comparison and transparency, the full list of country-specific estimates is provided in the supplementary materials.

Subgroups were characterised as 'background' or 'elevated exposure'. Some studies pooled these subgroups together without calculating separate subgroup means. In these cases, we conservatively coded the sample as 'elevated exposure'. However, this presents an artificially low BLL for the 'elevated exposure' subgroup. Samples from certain mining communities or smelter towns for example were pooled across areas of high and low ambient contamination when only a subsample lived in places that could be characterised as a hotspot. One example is Oruro, Bolivia

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where the studies report BLLs from a wide geographic area as representative of hotspot exposure. However in reality, the environmental contamination is much more confined affecting only a smaller subset of the population (Pure Earth, 2018).

Assessment of childhood BLLs cannot depend alone on national or regional estimates which fail to identify areas where lead exposure is disproportionately high. Pooling results over multiple sites increases statistical stability but also results in conservative estimates of BLLs. For example, a mass lead poisoning event in Nigeria resulted in BLLs in excess of 130 μg/dL (Dooyema *et al.*, 2012). When these estimates were pooled with BLLs from other elevated exposure groups in Nigeria the result was 58.5 μg/dL. A related limitation is our pooling of BLLs for all children < 18 years of age to calculate a representative BLL for each cohort of 5-year-old children. Because BLLs tend to decrease with age, this likely resulted in an underestimate of exposure.

There were certain limitations related to the availability of economic data. These are reported in detail in the supplementary materials and were unlikely to discernibly influence the results; in most cases, reasonable imputations or proxies could be made.

There are implicit limitations associated with making these sorts of projections. The models that underly our study are based on observations in high-income countries. We have tried to adapt these to LMICs by using country-specific economic and demographic data. We have also endeavoured to be clear about the uncertainty in our analysis and have presented ranges where possible. Finally, we have made an effort to present conservative estimates by valuing an IQ point at 1.4% of lifetime earnings and using more conservative estimates of attributable IQ point loss. The results may in fact be an underestimate of losses. We have made our full dataset available in the supplementary materials and encourage further analysis and interpretation by other researchers.

5. Conclusions

This study found USD 305–499 billion (2019 USD) in lost economic productivity attributable to paediatric lead exposure in the 121 LMICs for which values could be calculated. This finding is consistent with previous estimates and further validates those efforts with a substantially expanded dataset. Differences in the findings resulted primarily from the use of a more conservative dose–response model in the present study. Improved reporting of BLLs is essential to refine future estimates and could be facilitated through a centralised registry of study results.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1744133125100121

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Competing interests. Bret Ericson declares that he is an independent technical expert that consults for UN organisations and NGOs on chemicals exposures, including those relating to lead. Mary Jean Brown declares that she provides technical assistance and advice to Meridian Biosciences makers of the blood lead point of care instrument LeadCare II. Meridian Biosciences is not referenced in this document. Dr. Brown has also provided technical assistance for plaintiffs in legal cases involving lead exposure.

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