Cigarette taxation and socioeconomic inequalities in under-5 mortality across 94 low-income and middle-income countries: a longitudinal ecological study

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Summary

Background Although increasing cigarette taxes is known to improve child survival, there are few data on their effect on socioeconomic inequalities in child mortality. We investigated the association between cigarette taxation and socioeconomic inequalities in mortality in children younger than 5 years (hereafter referred to as under-5 mortality) in low-income and middle-income countries (LMICs).

Methods This was a longitudinal ecological study. We linked country-level annual data on 94 LMICs, as defined by the World Bank, and annual data on under-5 mortality by wealth quintile from the UN Inter-agency Group for Child Mortality Estimation from 2008 to 2020. We used fixed-effect panel regression models to assess the association of cigarette taxes with absolute and relative inequalities in under-5 mortality by wealth quintile.

Findings Increasing total cigarette tax by 10-percentage-points was associated with reduced under-5 mortality rates in all wealth quintiles. Raising total cigarette tax from 0·0–24·9% to 25·0–74·9% and 75·0% or more of their total retail value was associated with 3·8% (95% CI 0·2 to 7·3) and 7·6% (1·4 to 13·4) decreases in absolute inequality in under-5 mortality, respectively. This finding was mainly attributable to specific tax, which was associated with a 1·4% (0·3 to 2·6) reduction in absolute inequality for each 10-percentage-point increase. We estimated that raising total cigarette taxes to 75·0% or more in all 94 LMICs could have averted 281 017 (196 916 to 362 301) under-5 deaths in 2021.

Interpretation High cigarette taxes are associated with a large decrease in absolute inequality in child mortality in LMICs. These findings support raising cigarette taxes to the WHO-recommended 75% or more of the retail value to protect the poorest children.

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Introduction

Second-hand smoke exposure from tobacco smoke in utero or during childhood is an entirely preventable contributor to morbidity and premature mortality, causing an estimated 5·6 million disability-adjusted life-years and approximately 200 000 annual deaths in children younger than 5 years (hereafter referred to as under-5 mortality) globally.[1–3] Smoking prevalence and children's exposure to second-hand smoke are often higher among people of lower socioeconomic status and increase the risk of adverse child health outcomes, including mortality.[4–8] This is true for maternal smoking during pregnancy, as well as antenatal and postnatal second-hand smoke exposure (appendix pp 1–2).[4–8] Low-income and middle-income countries (LMICs) bear the greatest burden of child mortality, with an estimated 90% of global under-5 mortality occurring in these settings.[9,10] Moreover, the majority of smokers reside in LMICs, further emphasising the crucial role of tobacco control policies in achieving the two UN Sustainable Development Goals: goal 3.2.1, aiming to improve under-5 mortality, and goal 10, aiming to decrease health inequalities.[11,12]

There is strong evidence supporting the effectiveness of tobacco control policies in improving overall child health and survival.[7,8,13,14] The MPOWER measures (monitor tobacco use; protect people from second-hand smoke; offer help to quit tobacco use; warn about the dangers of tobacco; enforce bans on tobacco advertising, promotion, and sponsorship; and raise taxes on tobacco) are key policies recommended by WHO as part of the Framework Convention on Tobacco Control to reduce demand for tobacco products.[15] Although all these policies are important and effective, according to WHO, raising taxes on tobacco is the most effective measure for reducing tobacco use.[16,17] Some studies conducted in both LMICs and high-income countries have shown their positive effect on overall child survival.[13,18–20] Despite this compelling evidence and widespread ratification of the Framework Convention on Tobacco Control (including

See Online for appendix

Research in context

Evidence before this study

Exposure to second-hand smoke in utero or in early childhood is a known risk factor for adverse child health outcomes, including under-5 mortality, and is a substantial contributor to socioeconomic inequalities in child health and survival. Raising taxes on cigarettes is an established measure to reduce smoking prevalence and children's exposure to second-hand smoke, and consequently improve overall child health and survival.

Two previous systematic reviews have highlighted the effect of raising cigarette taxes on inequalities in adult health and smoking behaviour, showing potential for reducing these disparities in the short term and long term. To explore whether similar effects might exist for child survival, we conducted a literature search on PubMed on Aug 22, 2024, using the terms: ("tobacco price*", "tobacco tax*", "cigarette price*", OR "cigarette tax*") AND ("ineq*" or "socio*") AND ("infant mortality" OR "neonatal mortality" OR "child mortality" OR "under-five mortality"), with no limits on dates or language. This search identified five studies, including single-country and multi-country assessments of links between changes in cigarette prices and taxes and overall childhood survival, all of which identified robust gains in child survival associated with increased cigarette taxes. However, none of the studies specifically examined the association between cigarette prices or taxes and inequalities in child survival. Therefore, it is unclear whether the benefits observed in adult outcomes extend to reducing inequalities in child survival.

Added value of this study

In this study, we used under-5 mortality data by socioeconomic income group from the UN Inter-agency Group for Child Mortality Estimation (UN IGME) on 94 low-income and middle-income countries (LMICs) from 2008 to 2020 to examine associations of total cigarette taxes and different types of cigarette taxes with inequalities in child survival. This is the first analysis linking changes in cigarette taxes and structure to inequalities in child survival. The use of UN IGME data allowed us to go beyond simply examining overall child survival and to incorporate socioeconomic variations in under-5 mortality. The data contained information on LMICs, where tobacco industry interference and child mortality tend to be high, and there is fewer research. Our study identified statistically significant reductions in socioeconomic inequalities in child mortality associated with raising cigarette taxes substantially (at least 75% of their total retail value), as well as reductions in under-5 mortality rates across all wealth quintiles. This finding was mainly attributable to increases in specific tax.

Implications of all the available evidence

Building on the studies that have identified associations between raising cigarette taxes and improved overall child survival, our study indicates that raising cigarette taxes has the potential to reduce inequalities in child survival, especially if raised substantially, as well as improve child survival across all wealth quintiles. These findings emphasise the importance of meeting the WHO-recommended 75% minimum tax level of the total retail value threshold. Raising taxes on cigarettes could contribute to the UN's Sustainable Development Goal 3.2.1 to improve under-5 mortality, and goal 10 to decrease health inequalities.

182 countries, covering more than 90% of the world's population), the majority of countries have not implemented these policies, particularly in terms of levying sufficiently high taxes.[1] By 2022, only 41 countries (21% of all 195 countries globally)—16 of which are LMICs—had raised total cigarette taxes to the WHO-recommended level of at least 75% share of the retail value of cigarettes.[1]

The equity effect of cigarette taxation on child survival is unknown.[1,21,22] Existing research on cigarette taxation and social inequalities has focused on socioeconomic differences in the smoking behaviour of adults.[23–29] Although most studies found a positive equity effect on adults, some studies have raised concerns that the positive health effects associated with cigarette taxation might not have effectively reached lower socioeconomic groups in the long run because they switch to cheaper products (eg, roll-your-own cigarettes) or cannot sustain quitting.[7,13,25,27–30] Furthermore, the majority of these studies were from high-income countries and therefore might not be generalisable to LMICs.[23,24,29] Most importantly, a direct evaluation of the effect of cigarette taxation on social inequality in child survival is needed because studies focusing on social inequalities in adult smoking behaviour might not be generalisable to child survival due to complex causal pathways between the two factors.[13,14,18,20] It is crucial to understand the equity effect of tobacco control interventions to protect vulnerable children from the tobacco industry, which has shifted its focus to expand markets in low-income populations.[30,31–33] Because low-income populations tend to disproportionately bear the burden of tobacco-related morbidity and mortality, discovering whether or not tobacco control measures reach the most vulnerable groups is crucial to reduce tobacco-related health disparities.

Our study aims to bridge this knowledge gap by estimating the association between changes in cigarette tax level and structure, and absolute and relative inequalities in under-5 mortality within and between countries. With unique annual data on under-5 mortality rates by socioeconomic groups across various countries and multiple years, we performed the first analysis of the relationship between raising cigarette taxes on socioeconomic inequalities in child survival in LMICs.

Methods

Study design and data sources

Country-level data on 132 LMICs, as defined by the World Bank, were gathered between 2008 and 2020 for this longitudinal ecological study.[34] Data on under-5 mortality by wealth quintile were sourced from the UN Inter-agency Group for Child Mortality Estimation (UN IGME) and were available annually from 2008 to 2020 through the WHO Health Inequality Data Repository for all LMICs.[35,36] UN IGME data were compiled from all available sources, including censuses, vital registration data, and household surveys, and were modelled using a Bayesian spline regression model.[35,36] Biennial data on MPOWER measures and cigarette taxes were available from 2008 to 2020 at the country level and were extracted from the WHO Global Health Observatory.[3] Data on all other covariates were obtained from the World Bank and were available annually between 2008 and 2020.[37] This study used anonymised aggregated data from publicly available resources, therefore ethical approval was not required.

Variables

The outcome variables in this study were: (1) under-5 mortality—defined as the estimated number of children who died before the age of 5 years per 1000 livebirths—by wealth quintiles one to five (quintile one being the poorest and quintile five being the wealthiest); (2) the absolute difference in under-5 mortality between the wealthiest and poorest wealth quintiles within countries; and (3) the relative inequality in under-5 mortality—namely, the proportional difference in under-5 mortality between the wealthiest and poorest wealth quintiles (table 1). Measuring both absolute and relative inequalities in under-5 mortality is important because each highlights different aspects of inequalities. The relative measure focuses on equality in itself because it is independent of the rates in the lowest and highest quintiles, whereas the absolute measure emphasises the size of the difference in the rates between the lowest and highest quintiles. These measures can move in different directions—for example, absolute inequalities might decrease while relative inequalities increase if absolute declines in

	Data source	Definition	Period	Frequency
Outcomes				
Under-5 mortality rate by economic status (wealth quintile)	WHO	The number of children younger than 5 years who die per 1000 livebirths, by wealth quintile	2008–20	Annual
Absolute inequalities in under-5 mortality	WHO	The absolute difference between the poorest (quintile 1) and wealthiest (quintile 5) wealth quintiles refers to the difference in under-5 mortality rates between these two groups calculated for each year between 2008 and 2020, expressed as deaths per 1000 livebirths	2008–20	Annual
Relative inequalities in under-5 mortality	WHO	The relative difference between the poorest (quintile 1) and wealthiest (quintile 5) wealth quintiles refers to the proportional difference in under-5 mortality rates between these two groups calculated for each year between 2008 and 2020, expressed as deaths per 1000 livebirths, as shown in this equation: (U5 mortality Q1–U5 mortality Q5)/(U5 mortality Q5)	2008–20	Annual
Exposure variables				
Total tax	WHO	Total cigarette tax as a percentage of the retail value (per 10%), including specific tax plus ad valorem plus other taxes	2008–20	Biennial
Specific tax	WHO	Specific excise tax (ie, fixed amount per cigarette or per weight of each cigarette) as a percentage of the retail price (per 10%)	2008–20	Biennial
Ad valorem	WHO	Ad valorem excise tax (ie, a percentage of the factory price or retail value) as a percentage of the retail value (per 10%)	2008–20	Biennial
Other taxes (import duties, value added tax, and other taxes)	WHO	Value added tax or sales (ie, general tax on consumption), import duties (ie, a tax on imported goods that are destined for domestic consumption), and other taxes (ie, differently named taxes) as a percentage of the retail value (per 10%)	2008–20	Biennial
MPOWER measures				
Protect people	WHO	Five-point scale based on WHO evaluation about protecting people from tobacco smoke	2008–20	Biennial
Offer help to quit	WHO	Five-point scale based on WHO evaluation about offering help to quit tobacco use	2008–20	Biennial
Warning about dangers: health warnings	WHO	Five-point scale based on WHO evaluation about health warnings about tobacco	2008–20	Biennial
Warning about dangers: mass media campaigns	WHO	Five-point scale based on WHO evaluation about mass media campaigns against tobacco	2008–20	Biennial
Enforce bans	WHO	Five-point scale based on WHO evaluation about enforcing bans on tobacco advertising, promotion, and sponsorship	2008–20	Biennial

(Table 1 continues on next page)

	Data source	Definition	Period	Frequency
(Continued from previous page)				
Additional covariates for under-5 mortality				
Time	Not applicable	Calender year	2008–20	Annual
Gross domestic product	World Bank	Gross domestic product per person, per 1000 parity purchasing power (current international dollars)	2008–20	Annual
Fertility rate	World Bank	The average number of children born to a woman (given women survive the childbearing age and fertility is in line with age-specific fertility rates of the specified year)	2008–20	Annual
Rural population	World Bank	The proportion of the population living in rural areas, as defined by national statistical offices (per 10% of the population)	2008–20	Annual
Drinking water	World Bank	The proportion of the population with access to basic drinking water (ie, collection time <30 min; per 10% of the population)	2008–20	Annual
Health expenditure	World Bank	Current health expenditure per person, per 1000 parity purchasing power (current international dollars)	2008–20	Annual
Female primary education completion rate	World Bank	The ratio of the number of new female entrants in the last grade of primary education (regardless of age) and the number of girls at the entrance age for the last grade of primary education (per 10% of the population)	2008–20	Annual
Clean cooking	World Bank	The proportion of the population with access to clean fuels and technologies (those that attain the fine particulate matter [PM2·5] and carbon monoxide [CO] levels recommended in the 2021 WHO global air quality guidelines) for cooking (per 10% of the population)	2008–20	Annual
CO_2 emissions, kiloton	World Bank	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring	2008–20	Annual

MPOWER measures are further detailed in the appendix (p 3). Current international dollars refers to values expressed in international dollars for each respective year in our dataset.

Table 1: **Full definitions, data sources, periods, and reporting frequencies for all included variables**

under-5 mortality are larger but relative declines are smaller in the more disadvantaged compared with the most advantaged groups.[38]

Our main exposure variable was total cigarette tax as a percentage of the average retail value for a 20-pack of cigarettes in each country as a continuous variable. We also considered total cigarette tax as a categorical variable (0·0–24·9%; 25·0–74·9%; and ≥75·0% of the retail value [ie, the WHO-recommended level of taxes]). Finally, instead of total tax, we used three variables measuring the different types of tax (specific tax [ie, tax charged per quantity, such as per pack, regardless of price]; ad valorem [ie, tax charged as a percentage of the value of the product]; and other taxes, including import duties and value added tax) as continuous variables separately. We ran separate models for each separate exposure, as well as for each outcome variable (wealth quintiles 1–5, and absolute and relative inequality).

The covariates included in this study were: MPOWER tobacco control measure scores that indicated the existence of the measures based on a five-point scale (excluding monitoring tobacco use due to the irrelevance for the outcome, and raising taxes on tobacco due to redundancy, given our exposure variables also measure taxes; appendix p 3), time (calendar year as a categorical variable), gross domestic product parity purchasing power per person, countries' fertility rates (average number of children born to a woman each year), percentage of the population living in rural areas, percentage of the population with access to basic drinking water, health expenditure per person, female primary education completion rate, percentage of the population with access to clean fuels and technologies for cooking, and national CO_2 emissions. All control variables were chosen based on existing literature that had shown their effect on child survival.[13,14,39,40]

All outcome variables, aside from relative inequality in under-5 mortality, were transformed to the log scale because they were not normally distributed. Consequently, the results from the panel regression models are presented as exponentiated β coefficients (excluding relative inequality in under-5 mortality, because it is not on the log scale) and should be interpreted as the percent change in the outcome associated with one-unit changes in the exposure variables.

Some variables were transformed to improve the interpretation of the results. All types of cigarette tax (total tax, specific tax, ad valorem, and other taxes), rural population, access to clean fuels and technologies for cooking, and access to basic drinking water were recoded to reflect a 10-percentage-point change in their values. Additionally, gross domestic product parity purchasing power and health expenditure were

transformed to reflect the percent change per 1000 purchasing power parity-adjusted increase (in current international dollars, which refers to values expressed in international dollars for each respective year in our dataset). The MPOWER measure W consists of two scales (warn about the dangers of tobacco: health warnings and mass media campaigns) that were averaged to obtain one singular W score. To simplify the model, the P, O, W, and E scores were summed into one single composite score.

Missing data

Missing observations for years where data were not reported were imputed through linear interpolation between years with available data. Countries were automatically excluded from the models by the statistical software if there were no observations for all years for any of the variables (N=34).

Data analysis

We used fixed-effects panel regression models to test the association between cigarette taxes and under-5 mortality by wealth quintile. Panel regression models capture changes over time and account for the clustered data (country-level observations) collected repeatedly over time.[13,14,20,41] The fixed-effect specification uses dummy variables to account for time-invariant, country-level potential confounding variables that are not possible or feasible to measure.[42] The choice of the fixed-effect specification over the less restrictive random-effect specification was supported by Hausman tests.[42]

Non-lagged models were chosen as the main model, similar to previous studies on the association between cigarette taxes and child survival.[13,20] Nevertheless, we tested an up to 3-year time lag to account for any delayed effects or cumulative effects of taxation on under-5 mortality using Akaike information criterion and Bayesian information criterion; however, the lags did not improve the fit of the model (appendix p 4).

We estimated the under-5 mortality that could have been avoided in 2021 if each country included in the analysis would raise taxes on cigarettes to the minimum WHO recommendation of 75% of their retail value (appendix p 5). For each country that did not yet reach the recommended level per quintile, we applied quintile-specific effect estimates (ie, expressing changes in the outcome by a one-percentage-point increase in taxation as a percentage of the retail value of cigarettes) from our fixed effect model defining taxes as a continuous measure to the difference between each country's cigarette tax and the 75% threshold, and to the country's estimated number of under-5 deaths disaggregated by wealth quintile. Each country's estimated deaths averted were then summed up per quintile.

We performed several sensitivity analyses with total tax as the exposure variable where we tested: (1) a 1-year time lag to check for any potential delayed policy effect after implementation; (2) excluding 2020 data to exclude any potential effect from the COVID-19 pandemic; (3) no adjustments for covariates to see how they affected the results; (4) no controlling for time; (5) no missing observation imputation to see whether linear interpolation changed the results; (6) including the P, O, W, and E measures as individual scores to ensure the composite score had the same effect; (7) including the MPOWER measure M (monitor tobacco use) to see if its exclusion affected the results; (8) including total tax categorised into four equal percentage groups as opposed to three; (9) no adjustment for covariates with total tax as a categorical variable; and (10) no controlling for time with total tax as a categorical variable. All analyses were performed with Stata (version 17.0).

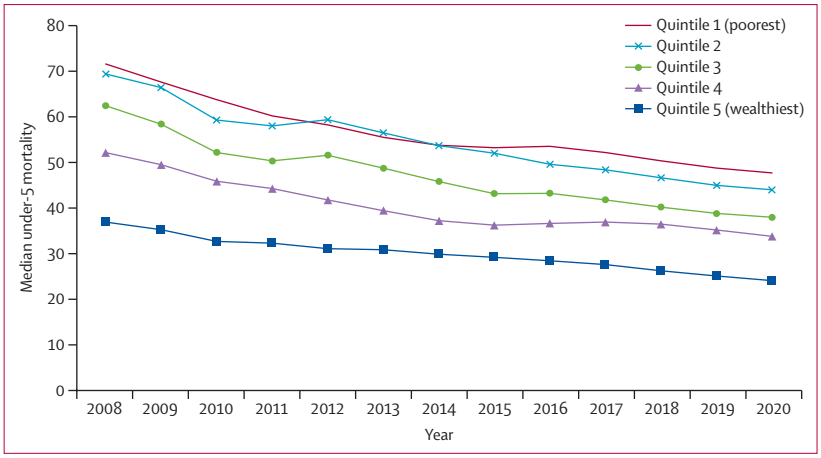

Figure 1: **Median under-5 mortality rates (per 1000 livebirths) by wealth quintile from 2008 to 2020 in 94 low-income and middle-income countries**

	Total tax (IQR)	Specific tax (IQR)	Ad valorem (IQR)	Other taxes including import duties, value-added tax, and other taxes (IQR)
2008	39·0% (25·0–52·0)	0·0% (0·0–25·5)	3·0% (0·0–18·0)	13·0% (9·5–16·0)
2010	39·0% (25·0–55·0)	5·0% (0·0–30·0)	2·0% (0·0–17·0)	14·0% (10·0–16·0)
2012	36·0% (28·0–52·0)	8·0% (0·0–24·0)	2·0% (0·0–17·0)	14·0% (9·0–16·0)
2014	38·0% (28·0–54·0)	12·0% (0·0–29·0)	0·0% (0·0–16·0)	14·0% (11·0–16·0)
2016	39·0% (28·0–54·0)	14·0% (0·0–33·0)	2·0% (0·0–15·0)	14·0% (10·0–16·0)
2018	43·0% (31·5–54·5)	16·5% (0·0–35·5)	2·5% (0·0–15·0)	14·0% (9·5–17·0)
2020	44·0% (34·0–58·0)	18·0% (0·0–36·0)	3·0% (0·0–16·0)	14·0% (11·0–17·0)

Table 2: **Median total cigarette taxes (as a percentage of the retail value) for each type of tax biennially from 2008 to 2020 in 94 low-income and middle-income countries**

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

Of the 132 LMICs we gathered data from, data from 94 countries were included in the panel regression

	Under-5 mortality					Inequality in under-5 mortality	
	Quintile 1 (poorest)	Quintile 2	Quintile 3	Quintile 4	Quintile 5 (wealthiest)	Absolute inequality	Relative inequality
10-percentage-point increase in total tax (% of retail value)	2·0 (1·4 to 2·6)	2·1 (1·5 to 2·7)	2·1 (1·4 to 2·7)	2·1 (1·5 to 2·7)	2·1 (1·5 to 2·7)	0·7 (–0·3 to 1·8)	0·0 (–0·2 to 0·2)
N	826	826	826	826	826	826	826
Total tax (% of retail value), categorical							
0·0–24·9%	Reference	Reference	Reference	Reference	Reference	Reference	Reference
25·0–74·9%	2·7 (0·6 to 4·8)	2·8 (0·6 to 5·0)	2·7 (0·5 to 4·9)	2·7 (0·5 to 4·8)	2·6 (0·4 to 4·8)	3·8 (0·2 to 7·3)	0·0 (–0·8 to 1·4)
≥75·0	6·0 (2·4 to 9·5)	6·3 (2·5 to 9·9)	6·1 (2·3 to 9·7)	6·1 (2·3 to 9·7)	5·8 (2·1 to 9·4)	7·6 (1·4 to 13·4)	0·1 (–1·3 to 0·2)
N	826	826	826	826	826	826	826
10-percentage-point increase in separate types of taxes							
Specific tax	2·6 (1·9 to 3·2)	2·7 (2·0 to 3·4)	2·6 (1·9 to 3·3)	2·6 (1·9 to 3·3)	2·6 (2·0 to 3·3)	1·4 (0·3 to 2·6)	0·1 (–0·2 to 0·3)
Ad valorem	1·2 (0·4 to 1·9)	1·1 (0·3 to 1·9)	1·2 (0·4 to 2·0)	1·3 (0·5 to 2·1)	1·3 (0·5 to 2·1)	–0·5 (–1·9 to 0·9)	–0·2 (–0·4 to 0·1)
Other tax	3·0 (2·0 to 3·9)	3·0 (2·0 to 4·0)	3·1 (2·1 to 4·1)	3·2 (2·2 to 4·2)	3·1 (2·1 to 4·1)	1·4 (–0·4 to 3·1)	–0·1 (–0·5 to 0·2)
N	826	826	826	826	826	826	826

Data are outcome variables (decrease in percentage point and 95% CIs). Data are decrease in percentage point and 95% CIs. Negative values indicate an increase in percentage point. This table contains only the coefficients for the main exposure variables (cigarette taxes). All models adjust for POWE tobacco control measures, time, gross domestic product parity purchasing power per person, percentage of the population living in rural areas, countries' fertility rates, percentage of the population with access to basic drinking water, health expenditure per person, female primary education completion rate, percentage of the population with access to clean cooking, and CO_2 emissions. POWE=WHO MPOWER measures (protect people from second-hand smoke, offer help to quit tobacco use, warn about the dangers of tobacco, and enforce bans on tobacco advertising, promotion, and sponsorship).

Table 3: **The association between total cigarette tax (% of retail value) and decreases in under-5 mortality in different wealth quintiles, and inequalities in under-5 mortality from 2008 to 2020 in 94 low-income and middle-income countries in the main models**

analysis from 2008 to 2020 (appendix p 6). Median under-5 mortality rates decreased between 2008 and 2020 across all wealth quintiles (figure 1; appendix p 7). Median under-5 mortality rates were highest in the poorest quintile (quintile 1), ranging between 71·5 (IQR 37·6–116·2) deaths per 1000 livebirths in 2008 and 47·6 (25·3–75·8) deaths per 1000 livebirths in 2020. This was substantially higher than in the wealthiest quintile, where median under-5 mortality rates ranged between 36·9 (17·6–72·0) deaths per 1000 livebirths in 2008 and 24·0 (12·0–42·3) deaths per 1000 livebirths in 2020.

Median tax percentages generally increased over the study period, with some variation depending on the type of tax (table 2). Median total tax rose from 39·0% (IQR 25·0–52·0) in 2008 to 44·0% (34·0–58·0) in 2020. Median specific tax also increased during the study period, from 0·0% (0·0–25·5) in 2008 to 18·0% (0·0–36·0) in 2020. Median ad valorem tax was consistent, with 3·0% (0·0–18·0) in 2008 and 3·0% (0·0–16·0) in 2020, although there was minor variation between years. Median other taxes were also fairly stable, increasing from 13·0% (9·5–16·0) in 2008 to 14·0% (11·0–17·0) in 2020. Of all the total tax observations, 16·5% were equal to or more than the WHO-recommended threshold of 75% of the total retail value.

When examining the association between changes in cigarette taxes and under-5 mortality, we found significant benefits to overall child survival in all models and wealth quintiles and a small, although statistically insignificant, decrease in absolute inequalities in under-5 mortality (0·7%; 95% CI –0·3 to 1·8; table 3). In the model where we interpreted total tax as a categorical variable, we found that increasing total tax from the 0·0–24·9% category to the 25·0–74·9% category was associated with consistent decreases in under-5 mortality in all quintiles, with the strongest effect in the second poorest quintile (2·8%; 0·6 to 5·0) and the weakest effect in the wealthiest (2·6%; 0·4 to 4·8). Increasing total tax from the 0·0–24·9% category to the 75·0% or higher category was associated with robust decreases in under-5 mortality, spanning from a 6·3% (2·5 to 9·9) decrease in the second poorest quintile to a 5·8% (2·1 to 9·4) decrease in the wealthiest. Statistically significant reductions in absolute inequality were found when raising the total tax to both the 25·0–74·9% and the 75% or more categories, with a 3·8% (0·2 to 7·3) decrease in the 25·0–74·9% category and a 7·6% (1·4 to 13·4) decrease in the 75% or more category. Raising cigarette taxes was not associated with a statistically significant decrease in relative inequality for any of the tax categories examined.

A 10-percentage-point increase in total cigarette tax was associated with nearly identical reductions in under-5 mortality across all wealth quintiles, with a decrease of 2·0% (95% CI 1·4–2·6) in the poorest quintile, and a 2·1% (quintile 2: 1·5–2·7; quintile 3: 1·4–2·7; quintile 4 and 5: 1·5–2·7) decrease in all other quintiles. We did not find evidence of statistically significant declines in absolute or relative inequalities in this model.

In the model with separate tax elements, a 10-percentage-point increase in specific tax was associated with a 1·4% (95% CI 0·3–2·6) decrease in absolute inequality in under-5 mortality as well as consistent declines in under-5

mortality across all wealth quintiles, with a slightly larger decrease in the second poorest quintile (2·7%; 2·0–3·4). Raising ad valorem tax by 10-percentage-points was associated with declines in under-5 mortality that ranged from 1·3% (0·5–2·1) in the wealthiest and second wealthiest quintiles to 1·1% (0·3–1·9) in the second poorest quintile. A 10-percentage-point increase in other taxes was associated with the most robust decreases in under-5 mortality of all the separate tax elements, spanning from a 3·2% (2·2–4·2) reduction in the second wealthiest quintile to a 3·0% (2·0–3·9) reduction in the poorest quintile. We did not find evidence of changes in relative inequality for separate tax elements.

Of the 94 countries in our analysis, 84 had not yet raised cigarette taxes to the WHO-recommended minimum of 75% of their retail value by the end of the study period. Based on our models, raising cigarette taxes to this level across these 84 countries could have averted an estimated 69 596 (95% CI 48 717–90 474) under-5 deaths in the poorest wealth quintile versus 36 156 (25 826–46 486) in the wealthiest quintile in 2021 (figure 2). Cumulatively across all wealth quintiles, an estimated 281 017 (196 916–362 301) under-5 deaths might have been avoided of the 4 721 418 reported under-5 deaths in the 94 countries in 2021.

Our sensitivity analyses presented results largely in line with our main findings (appendix pp 8–10). Associations were statistically significant across most models and directionally similar to the main models in that under-5 mortality was associated with raising cigarette taxes by 10-percentage-points in all wealth quintiles, although a statistically significant equity effect was only detected in the model without covariates and the model where we did not control for time.

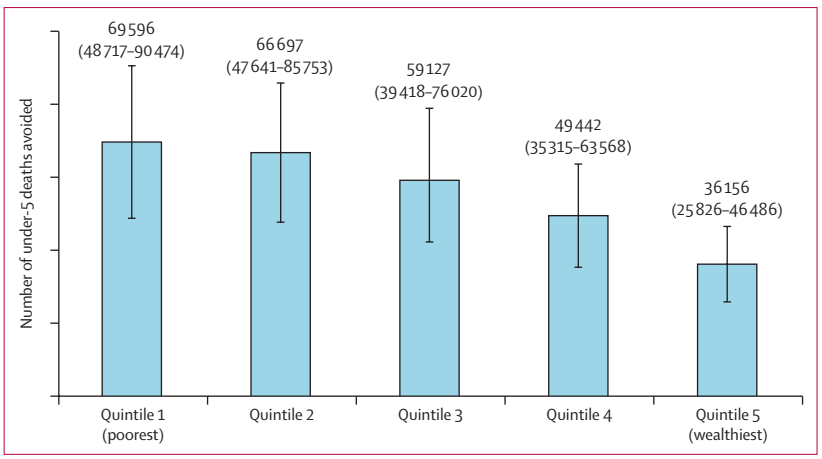

Figure 2: **The estimated absolute number of under-5 deaths (and 95% CIs) avoided by raising cigarette taxes to 75% of their retail value in 84 low-income and middle-income countries in 2021**

Discussion

In our panel analysis of 94 LMICs from 2008 to 2020, a marginal 10-percentage-point cigarette tax increase was associated with statistically significant reductions in under-5 mortality across all wealth quintiles. Statistically significant reductions in absolute inequality were found for categorically large tax increases, particularly when raised to at least 75% of their total retail value. In absolute terms, raising cigarette taxes to at least 75% of their retail value in the 84 countries in our analysis that did not yet reach this level could have avoided an estimated 281 017 (95% CI 196 916–362 301) under-5 deaths in 2021, with greater benefits accruing to the poorest quintile compared with the wealthiest one.

To our knowledge, this is the first examination of the relationship between cigarette taxation and under-5 mortality by socioeconomic group across multiple countries over time, going beyond the previously observed overall country-level effect.[7,13,18,35] Our study confirmed the findings of previous studies that cigarette taxes are beneficial for overall child survival,[13,18–20] and advances this work by showing that this overall positive effect can be found for all socioeconomic groups and has the potential to decrease inequalities in under-5 mortality. The main strength of our study is the use of novel UN IGME data on child survival disaggregated by socioeconomic group, which are comparable across countries and over time.[43]

Several mechanisms might explain why cigarette taxes affect children's mortality risk differently across socioeconomic groups. First, cigarette taxes can reduce smoking prevalence unevenly, with lower socioeconomic groups being more likely to quit smoking due to higher price elasticity (ie, they are more sensitive to price increases).[44] However, small tax increases might not have a meaningful effect on these groups because the tobacco industry can absorb some costs, keeping cigarettes affordable.[31] A substantial tax hike might more effectively reduce smoking in lower socioeconomic populations, helping to close the gap in smoking prevalence between poorer and wealthier individuals.[33,45] This reduction would likely decrease inequalities in neonatal exposure to second-hand smoke and maternal smoking, potentially lowering rates of infant mortality via improving outcomes such as stillbirth, sudden infant death syndrome, and complications such as premature birth or low birthweight,[4–8] or reducing child mortality from asthma or respiratory illnesses.[46–48] Some previous research has questioned whether higher cigarette taxes can lead to long-term improvements in socioeconomic inequalities in smoking prevalence because poorer individuals often have higher rates of relapse due to greater nicotine dependence, lower self-efficacy, and reduced quitting success compared with their wealthier counterparts.[29,44,49] Even if smoking rates decline similarly across all socioeconomic groups, children from lower socioeconomic status backgrounds might still benefit more because they tend to have higher exposure to tobacco smoke in public or workplace environments, both in utero and after birth.[4,50,51] Finally, although higher cigarette taxes or prices can reduce inequalities in

smoking prevalence, they might cause financial hardship among low socioeconomic status households that continue to smoke, which might negatively affect their ability to afford health-essential goods such as food or health care.[52–54] Some of these mechanisms might benefit the poorest people in society more, whereas other mechanisms do not, resulting in socioeconomic differences in children's mortality risk. Although this is outside the scope of the current study, future research is warranted to explore the link between cigarette taxes and the potential for unintended consequences, such as food insecurity, across income groups.

This study also extends the literature on the effect of tobacco control policies on socioeconomic inequalities in smoking behaviour to the effect of these policies on inequalities in child survival.[23–26,29,55,56] One systematic review found that the effect of raising cigarette prices on reducing smoking prevalence was greater among lower socioeconomic groups in the UK, USA, Canada, and Taiwan.[25] In contrast, another study conducted in the UK found no socioeconomic differences in quitting, despite greater price sensitivity among lower socioeconomic groups, probably due to switching to cheaper products or an inability to sustain quit attempts.[24] Moreover, in Australia, the effect of raising cigarette taxes on smoking prevalence had a larger immediate effect in lower socioeconomic groups compared with higher socioeconomic groups, but this positive effect was not sustained in the long run.[52] Our findings mirrored this complexity; we detected a statistically insignificant small decrease in absolute inequalities in under-5 mortality followed by a marginal increase in overall taxes, and a large statistically significant decrease in absolute inequalities when we examined higher levels of total tax with total tax as a categorical variable. Our findings therefore suggest that cigarette taxes should be raised a substantial amount to obtain a strong equity effect on child survival, which additionally emphasises the importance of raising cigarette taxes to the WHO-recommended 75% minimum of the total retail value threshold.

Although large tax increases were associated with statistically significant declines in absolute inequalities, associations with reduced relative inequalities were not detected. This suggests that, although taxes were associated with reduced mortality rates across all socioeconomic status groups—with the greatest absolute reductions in the lower socioeconomic status groups—the relative reduction in under-5 mortality was not greater in lower than in higher socioeconomic status groups. However, in LMICs, where overall under-5 mortality is rapidly declining, it is rare to find a policy that also reduces relative inequalities in mortality.[38]

When examining the effect of types of taxes individually, we found that raising specific taxes was statistically significantly associated with reduced inequalities in under-5 mortality. Specific taxes are specific to cigarettes, and raising them is the most recommended strategy by WHO to reduce smoking.[16,57] Raising specific taxes is more straightforward than ad valorem and other taxes because it does not require changes to entire tax systems, and is consequently less complicated to implement.[16,57] Moreover, it reduces the tobacco industry's ability to manipulate prices to maintain budget cigarettes on the market. Our findings add to existing evidence that raising specific taxes is most beneficial for population health, indicating the potential of an equity effect on under-5 mortality. Although our analyses indicate that each type of cigarette tax was associated with large benefits in overall child survival, only specific taxes were associated with a decrease in absolute inequalities. This is partly explained by other taxes (including import duties, value added tax, and other taxes) generally affecting other types of health behaviours as well, and as such should not be neglected as a potential measure to improve child survival.[13]

Our study has some limitations. Despite the use of fixed-effect models that account for unobserved time-invariable factors, and the inclusion of additional time-varying covariates, we were unable to control for some factors, such as the voluntary adoption of smoke-free homes, or for how covariates might vary between different socioeconomic status strata, therefore, some residual confounding cannot be ruled out. Under-5 mortality as an outcome measure is not perfect, because more factors—such as accidents or injuries—could occur in the first 5 years of life, whereas a measure such as infant mortality (the number of children who die before the age of 1 year) is less susceptible to this limitation. Nevertheless, under-5 mortality primarily consists of infant mortality (approximately 75% of under-5 mortality is infant mortality in LMICs), thus, the figures available for under-5 mortality could confidently be considered as a proxy for infant mortality figures, for which data disaggregated by socioeconomic status are not available.[37] To address the limitation of potential bias from the possible variable lag between exposure and outcome when using under-5 mortality as an outcome measure, we tested a 1-year time lag in our sensitivity analyses, which yielded directionally similar results as the main model. Data on under-5 mortality rates were necessarily modelled by the UN IGME and include uncertainty, which is not captured in our estimates. Nevertheless, this is the sole source of under-5 mortality panel data across multiple countries disaggregated by socioeconomic group and considered to be the most reliable source in the absence of real-world observation, with similar modelled data often used in related impact analyses.[14,58–61] We were not able to include data on taxes on other forms of tobacco, such as roll-your-own cigarettes or smokeless tobacco. As such, the overall effect of tobacco taxation is probably underestimated in our study, due to it focusing only on cigarette tax. Our study primarily used data aggregated at the country level, with the outcome

variables available disaggregated by income level only. Disaggregated data by sex or gender and race or ethnicity were not available, thus subgroup analysis based on these factors was not possible. Data on MPOWER measures—included in our models as covariates—describe the existence of tobacco control policies but do not convey their degree of implementation, which likely varies, and this should be considered as a limitation. Imprecision might have been introduced from missing data imputation on the exposure variables, although this was likely minimal because our sensitivity analysis without it indicated directionally similar findings. When interpreting the estimations of potential under-5 deaths avoided in 2021, it should be considered that the gradient shown in part reflects the larger number of absolute under-5 deaths that occur in poorer socioeconomic groups in general. Our estimates reflect many diverse countries and cannot be applied to individual countries or regions without caution. Future studies should explore regional variation in tobacco control policy implementation and the potential facilitators and barriers to their effective implementation.

Future research should also consider how the other MPOWER measures affect socioeconomic inequalities in under-5 mortality because they have also been recognised to have a positive effect on child health and survival, although their effect on socioeconomic inequalities on child health is unclear.[8,14,27,50,56] Considering the tobacco industry's interference and tendency to target vulnerable groups,[30,31,32] it is particularly prudent to gain a clearer understanding of the capacity to reduce mortality among the most vulnerable children through an array of tobacco control measures.

Although child mortality rates are declining globally, LMICs continue to have an unacceptably high burden of child mortality, particularly among more socioeconomically disadvantaged groups.[35] Our findings suggest that raising cigarette taxes might aid in meeting the aims of Sustainable Development Goals 3.2.1 and 10 by improving child survival and reducing inequality in child mortality by socioeconomic group. In addition, taxes generate government revenue, which means more can be spent on health programmes and health-care services.[57] These investments can further reduce smoking prevalence and enhance child survival rates. Raising cigarette taxes is the most affordable and effective tobacco control measure and has been shown to be effective in LMICs, yet the latest data from WHO show that it is the least-implemented MPOWER measure.[13,62] Our study adds to the existing body of evidence advocating for more countries to implement the WHO-recommended 75% minimum threshold and provides compelling new evidence that doing so might potentially reduce within-country inequality in child mortality in LMICs. This is unfortunately not a simple task because interference from the tobacco industry in LMICs is a major impediment to implementing cigarette tax policy. Spreading misinformation, lobbying, exaggerating their importance to local economies, threatening litigation, and using price-reducing promotions to offset tax increases are just a few of the tactics used by the tobacco industry to prevent tobacco control progress.[30,31,32] It is, therefore, crucial for global health organisations to advocate and support countries in their tobacco control efforts.

In our panel analysis of 94 LMICs from 2008 to 2020, raising total taxes on cigarettes by 10-percentage-points was associated with statistically significant overall decreases in under-5 mortality across all wealth quintiles. Categorically large increases in total tax were associated with statistically significant decreases in absolute inequalities in under-5 mortality, with the greatest effect seen when raised to the WHO-recommended level of ≥75%. These findings indicate the potential child survival gains and reduced inequality resulting from increasing cigarette taxes, and underscore the importance of reaching the WHO-recommended minimum level of cigarette taxation, equating to at least 75% of their total retail value. All children, regardless of their socioeconomic status, should be urgently protected from tobacco smoke.

Contributors

OSB: formal analysis (lead), data curation (lead), writing of the original draft (lead), writing, methodology, review, and editing of the manuscript. MKR: conceptualisation (lead), formal analysis, writing of the original draft, review, and editing of the manuscript. JVB: conceptualisation, formal analysis, writing, methodology, review, and editing of the manuscript. SH, AAL, and FTF: formal analysis, and writing, review, and editing of the manuscript. CM and FJvL: writing, review, and editing of the manuscript. All authors had access to the data used in this study. OSB and MKR directly accessed and verified the underlying data. MKR was responsible for the decision to submit the manuscript for publication.

Declaration of interests

We declare no competing interests.

Data sharing

This study used publicly available data that can be found online at https://data.unicef.org/topic/child-survival/under-five-mortality/#data, https://data.worldbank.org/, and https://www.who.int/data/gho.

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