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Short Report

Education and adult mortality in middle-income countries: Surprising gradients in six nationally-representative longitudinal surveys

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ABSTRACT

Background: There are large differences in adult mortality across schooling groups in many high-income countries (HICs). An important open question is whether there are similar gradients in adult mortality in middle-income countries (MICs), where schooling and healthcare quality tends to be lower and health-related behaviors are often not strongly patterned by schooling.

Methods: We present one of the first international-comparative studies on schooling differences in adult mortality across MICs using harmonizedlongitudinal data on adults ages 50+ from China, Costa Rica, Indonesia, Mexico, South Africa, and South Korea. We use Cox proportional hazards models to estimate differences in the hazard of mortality across schooling groups overall and separately by sex and broad age groups. We also estimate schooling gradients in smoking and body mass index to determine whether risk factor gradients potentially explain mortality patterns.

Results: Only adults with tertiary schooling have a consistent adult mortality advantage compared to those with no schooling. We do not find evidence that individuals with primary schooling have a lower hazard of mortality compared to individuals with no schooling in five of the six countries. The mortality advantage for individuals with secondary schooling is mixed, with evidence of lower mortality relative to those with no schooling in Mexico, South Africa, and South Korea. Gradients in BMI and smoking are inconsistent across countries and unlikely to explain mortality differences.

Conclusions: We find that adult mortality and risk factor gradients in MICs can be much different than the established patterns seen in modern HICs. Our results highlight that adult mortality gradients are not an inevitability and are not found in all populations. Understanding what factors give rise to inequalities in adult mortality and what can be done to minimize gradients while still ensuring continued mortality improvements in MICs is a crucial focus for research and policy.

1. Introduction

There are large and persistent differences in adult mortality across schooling groups in high-income countries (HICs) (Elo & Preston, 1996; Hendi, 2015; Luy et al., 2015; Martikainen et al., 2013; Meara et al., 2008; Montez et al., 2011; Spoerri et al., 2014; Steingrímsdóttir et al., 2012). For example, in the United States, there is a 10-year difference in life expectancy at age 25 between individuals with at least a college a degree and those with less than a high school education (Hendi, 2015). There are similarly sized disparities in many other HICs, including Finland (Martikainen et al., 2013), Norway (Steingrímsdóttir et al., 2012), Germany (Luy et al., 2015), and Switzerland (Spoerri et al., 2014). These findings have invigorated academic and public debates on the education gradient and the causes of socioeconomic disparities in adult mortality.

In contrast to HICs, research on mortality disparities in low- and middle-income countries (LMICs) has primarily focused on child mortality (Hajizadeh et al., 2014; Houweling & Kunst, 2009, p.; McKinnon et al., 2014; Schell et al., 2007). This is likely because until recently, LMICs had young populations and childhood causes of death were

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responsible for the greatest mortality burden. (Murray & Lopez, 1997; United Nations Department of Economic and Social Affairs, 2019). Over the coming decades, however, MICs are expected to age substantially due to historic reductions in fertility and progress against child mortality (Sudharsanan & Bloom, 2018). In the backdrop of these demographic changes, there are two important unanswered questions: (1) what is the relationship between schooling and adult mortality in MICs; and (2) is this relationship is similar to the education gradient in HICs?

The relationship between schooling and adult mortality observed in HICs may not apply to MICs. Due to poor schooling quality in many MICs (Barro & Lee, 2013; Kremer et al., 2013), more schooling may not translate to more education or improved income . Limited availability of high-quality healthcare (Kruk et al., 2018) may also inhibit more-schooled individuals from translating their health knowledge into better health. Both these reasons are based on a direct causal pathway between schooling and mortality; however, in HICs, schooling is associated with broader social inequalities that also affect mortality (Link & Phelan, 1995; Phelan et al., 2010). Given the recency of schooling expansions for older cohorts in MICs (Barro & Lee, 2015), schooling may not be a strong proxy for social advantage in these contexts. Unfortunately, existing evidence on schooling and adult mortality in MICs is limited and isolated to specific countries and causes of death (Ardington & Gasealahwe, 2014; Chapoto et al., 2012; Hidajat et al., 2007; Luo & Xie, 2014). Due to differences in study design and sample ages, the results from these studies are also difficult to compare across countries.

We present one of the first international-comparative studies on schooling differences in adult mortality across several MICs using nationally representative data. Our study takes advantage of an international effort to collect and harmonize longitudinal aging data and includes data on adults ages 50+ from China, Costa Rica, Indonesia, Mexico, South Africa, and South Korea. The primary aims of our study are to estimate the size of schooling differences in adult mortality, determine whether inequality differs by sex and age, assess the role of risk factors to schooling gradients, and ultimately examine whether there is a consistent pattern of inequality across the six countries.

2. Materials and methods

2.1. Data

Data are from multiple waves of six nationally representative surveys of adult health and aging: the China Health and Retirement Longitudinal Study (CHARLS), the Costa Rican Study on Longevity and Healthy Aging (CRELES), the Indonesian Family Life Survey (IFLS), the Mexican Health and Aging Study (MHAS), the South African National Income Dynamics Study (NIDS), and the Korean Longitudinal Study of Aging (KLoSA). We include South Korea because it was an MIC for the majority of the life course of KLoSA cohort members, including when they were in school. Appendix I provides information on the timing of survey waves and sampling procedures for each study. Since our focus is on adult mortality, we restrict our sample to adults ages 50+, with the exception of the CRELES which focused on individuals 65+. We drop individuals with missing follow-up information, although this share is less than 10% for all six and less than 5% for three of the six surveys (share missing shown in Appendix VI).

2.2. Measuring mortality

For each data source, mortality for individuals in the baseline wave is reported by a family member during a follow-up wave of data collection. The CHARLS, CRELES, IFLS, MHAS, and KLoSA surveys report an exact date of death for the deceased individual while for the NIDS survey, we estimate date of death as halfway between survey waves. Individuals who did not die between survey waves were right censored at their last observed interview date.

2.3. Measuring schooling

Individuals in each survey reported their highest completed level of schooling based on the schooling categories used in their country. We harmonized schooling categories across countries using the International Standard Classification of Education (ISCED) (UNESCO Institute for Statistics, 2012) into the following groups: no completed schooling, primary schooling, secondary schooling (combining the lower-secondary and upper-secondary ISCED groups), and tertiary schooling (Appendix II lists the schooling categories for each survey and how they were classified into these groups). In sensitivity analyses (Appendix VII), we present results based on approximate tertiles of completed years of schooling. All schooling classifications were self, or household head, reported.

2.4. Estimating the relationship between schooling and mortality

Since the time between survey waves varied across surveys, we use information on date of interview, date of death, and date of censoring to first convert all data to a person-month survival time format. Therefore, we model the hazard of mortality as the one-month probability of death across all surveys.

We begin by calculating and describing age-standardized mortality rates by level of schooling and sex. Next, we estimate schooling differences in the hazard of mortality using a Cox proportional hazards regression with indicator variables for the some primary, some secondary, and greater than secondary schooling groups. The estimated coefficients correspond to the hazard ratio of mortality relative to the no schooling group. Since our interest is in the observed schooling gradient, which is a non-causal association between schooling and mortality that captures observed disparities in mortality, all models only adjust for age (indicator variables for five-year age groups between ages 50 and 85 with the final age group including all individuals ≥ 85) and sex.

To investigate whether the relationship between schooling and mortality varies by important population subgroups, we then repeat this analysis stratified by sex and broad age group (ages 50–64 and 65+) separately.

2.5. Estimating the relationship between schooling, smoking, and body mass index

To investigate whether common mortality risk factors vary across schooling groups in MICs, we also estimate schooling differences in the probability of ever smoking and body mass index (BMI). As with the mortality model, since our interest is in the observed differences, we only adjust for five-year age group and sex.

2.5. Robustness checks and diagnostics

We conduct a number of diagnostic and robustness checks to evaluate the quality of the mortality data in each survey and determine how missingness between surveys might potentially affect our results (Appendices III-VI). We also re-estimate our main figure combining the none and primary schooling groups and using a relative measure of schooling (approximate tertiles of years of schooling) (Appendix VII).

3. Results

3.1. Description of countries and surveys

The population of adults ages 50+ varies substantially in the six countries from 370 million in China, between 8 and 38 million in Indonesia, Mexico, South Africa, and South Korea, to just 833,198 in Costa Rica (Table 1). However, the share of the population above the age of 50 is substantial in all six countries and ranges between 15 and 19% for Costa Rica, Indonesia, Mexico, and South Africa, to 27% for China,

Table 1
Description of the countries and sample characteristics.

Country	Population of adults ages 50+ (% of total pop)	World Bank Income Group	Sample Size (Person-months)	Median age (IQR)	Percent Female	Number of deaths	Missing information (% of eligible)
China	369,955,772 (27%)	UMI	12,134 (585,700)<	61 (56–68)	51%	979	1480 (10.9%)
Costa Rica	833,198 (19%)	UMI	2603 (100,508)	75 (68–83)	54%	504	220 (7.8%)
Indonesia	38,021,236 (16%)	LMI	6969 (511,640)	60 (54–69)	54%	1606	65 (0.92%)
Mexico	20,981,687 (17%)	UMI	13,884 (481,625)	64 (57–72)	57%	1061	761 (5.2%)
South Africa	7,876,953 (15%)	UMI	3894 (265,039)	60 (54–69)	65%	966	226 (5.5%)
South Korea	13,775,429 (28%)	HI	7615 (500,323)	64 (57–71)	56%	804	806 (9.6%)

and 28% for South Korea. At the time of the surveys, four of the six countries were classified as upper-middle-income, with Indonesia (lower-middle-income) and South Korea (high-income) as the exceptions.

3.2. Schooling distribution

There is wide international variation in the proportions with no schooling, with the lowest levels among South Korean men (10%) and the highest among Chinese women (68%) (Fig. 1). The share of individuals with tertiary schooling is generally low, with the highest share among South Korean men (15%) and the lowest among Chinese women (1%). Levels of primary schooling are moderate across groups (between 15 and 69%); Costa Rica is the primary exception to this pattern with primary schooling levels of 66% for men and 69% for women. We do not find consistent evidence of sex differences in schooling across countries, with prominent differences in China, Indonesia, and South Korea and but not in Costa Rica, Mexico, and South Africa.

3.3. Relationship between schooling and adult mortality

There are important differences in both the level and shape of age-standardized mortality rates across sex, schooling groups, and countries (Fig. 2). South African men have the highest levels of mortality, with age-standardized mortality rates as high as 0.08 [0.072, 0.090] deaths per person year. Conversely, mortality is lowest among South Korean women with mortality ranging from just 0.003 [-0.001, 0.007] to 0.017 [0.014, 0.021] deaths per person year. With the exception of South African men, absolute schooling gradients in age-standardized mortality rates are flat to small in magnitude in most countries with the only substantial drops occurring among individuals with tertiary schooling. For example, among Mexican women, age-standardized mortality rates are 0.026 [0.022 0.031], 0.026 [0.024, 0.030], 0.020 [0.014,0.028], and 0.011 [0.003, 0.020] when moving from no schooling to tertiary schooling respectively.

The results from the Cox regression models mirror the age-standardized mortality-rate patterns (Fig. 3). Importantly, the ratio scale creates more prominent gradients in South Korea, where due to low absolute levels of mortality, absolute differences are less pronounced. We find that only adults with tertiary schooling have a consistent adult mortality advantage compared to those with no schooling. With the exception of South Korea, we find little evidence that individuals with primary schooling have a lower hazard of mortality relative to those with no schooling (China: 0.91 [0.77,1.09]; Costa Rica: 1.00 [0.81,1.24]; Indonesia: 1.00 [0.89, 1.14]; Mexico: 1.00 [0.87, 1.15]; South Africa: 0.86 [0.72, 1.04]; South Korea: 0.77 [0.65, 0.92]).

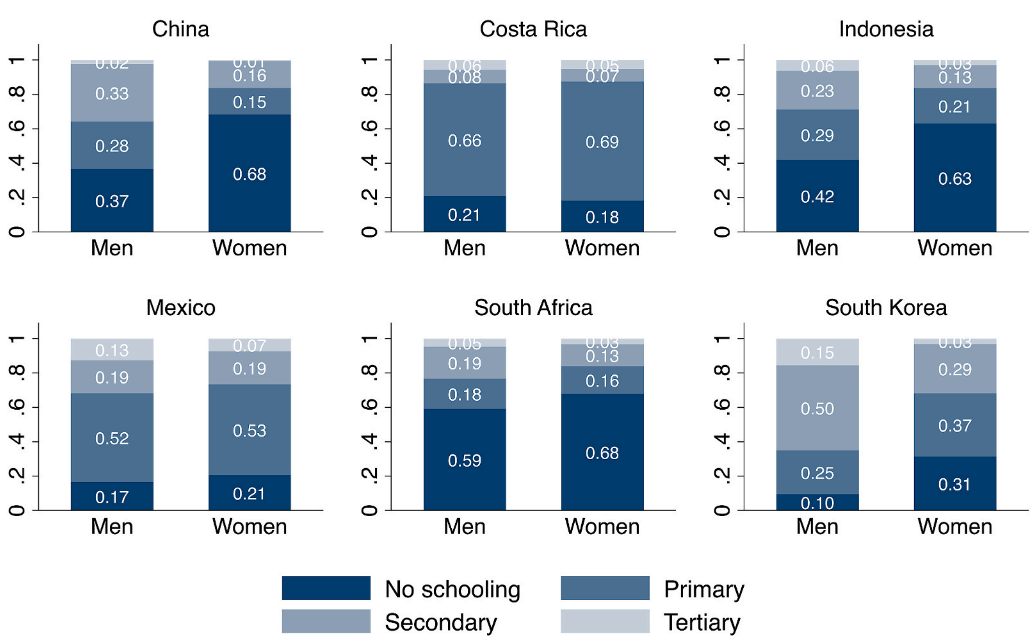

Fig. 1. Distribution of schooling by sex and country.[a]Data years: China (2011), Costa Rica (2005), Indonesia (2007), Mexico (2012), South Africa (2008), and South Korea (2006).

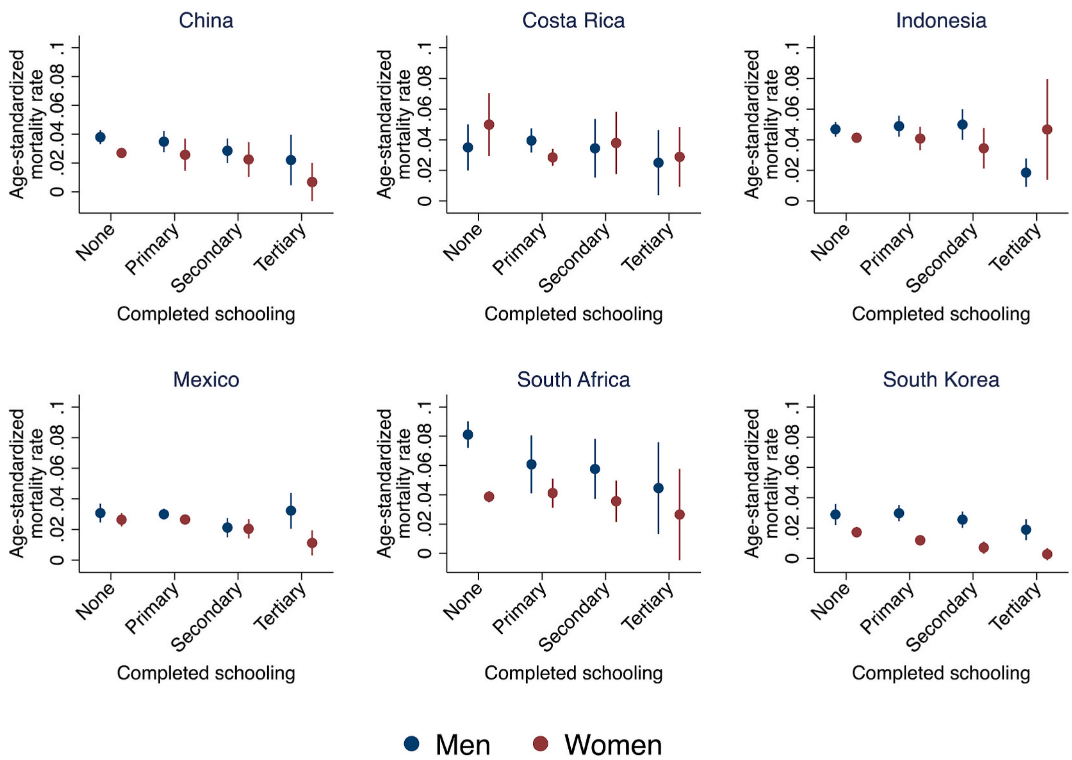

Fig. 2. Age-standardized mortality rates by sex, schooling, and country. [a]Results are presented as deaths per person-year. [b]Error bars represent 95% confidence intervals. [c]We used the overall population distribution across the six countries as the standard.

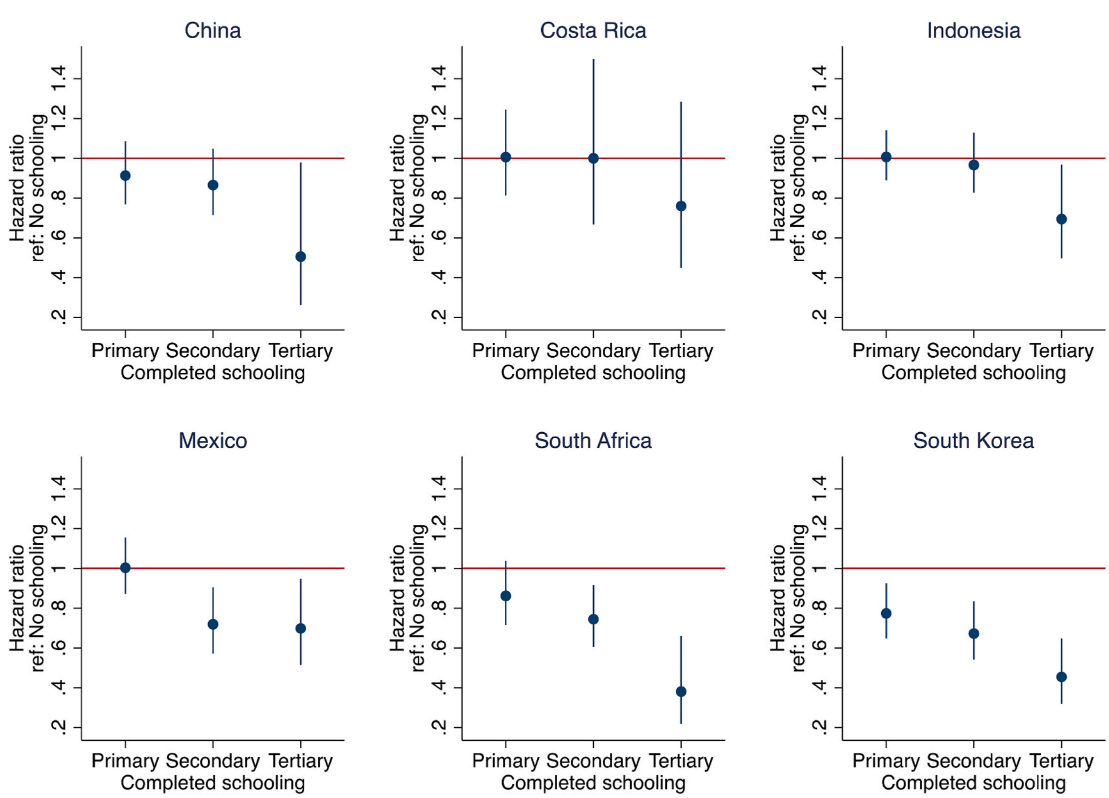

Fig. 3. Association between schooling and mortality. [a]Results are presented as hazard ratios relative to individuals with no schooling. [b]Error bars represent 95% confidence intervals. [c]Estimates are from a Cox Proportional Hazards model with controls for age (dummies with 5-year groups) and sex.

The relationship between secondary schooling and mortality is mixed across countries with little evidence of important differences in China (0.87 [0.71, 1.05]), Costa Rica (1.00 [0.67, 1.50]), and Indonesia (0.97 [0.83, 1.13]), but evidence of a slight mortality advantage in Mexico (0.72 [0.57, 0.90]), South Africa (0.74 [0.61, 0.92]), and South Korea (0.67 [0.54, 0.83]). Individuals with tertiary schooling have a hazard of mortality that is approximately 30% lower in Indonesia (0.69 [0.50, 0.97]) and Mexico (0.70 [0.51, 0.95]), approximately 50% lower in China (0.50, [0.26,0.98] and South Korea (0.45 [0.32, 0.65]), and 62% lower in South Africa (0.38 [0.22, 0.66]). Costa Rica is the primary exception to most of these patterns, with virtually no difference in the hazard of mortality across any of the schooling groups.

We find similar results for secondary and tertiary schooling groups when combining the none and primary schooling groups to be the reference category suggesting that the mixed results for secondary schooling are not just driven by the selectivity of the no-schooling group. Similarly, when using a relative measure based on years of schooling (approximate tertiles of years of schooling) only the highest tertile displays a consistent association with mortality relative to the lowest tertile (Appendix VII).

3.4. *Sex- and age-interactions in the relationship between schooling and mortality*

There are three important sex-differences in the relationship between schooling and mortality, although the magnitude of these differences is not consistent across countries (Fig. 4). First, we find that among Indonesian women and Mexican men, even those with tertiary schooling do not have a mortality advantage relative to those with no schooling. Second, there is a stronger gradient among South African men than women, with evidence of a schooling advantage starting with primary schooling for men. Lastly, the schooling gradient in South Korea is steeper at all levels for men than for women.

There is some evidence of an age difference in the relationship between schooling and mortality in Mexico, South Africa, and South Korea (Fig. 5). While statistically imprecise, the estimates suggest that the association between schooling and mortality is more pronounced for individuals between ages 50 to 65 when compared to individuals age 65+. This flattening of gradients at older ages is also present when comparing absolute, rather than relative, schooling differences (Appendix VIII).

3.5. *Relationship between schooling, smoking, and body mass index*

There is a mixed relationship between schooling and the age-sex-standardized prevalence of smoking across countries (Fig. 6). There are moderate smoking gradients in Indonesia and South Korea, with a decreasing prevalence between each schooling group. In contrast, in China and South Africa, levels of smoking are similar for those with none, primary, and secondary schooling and only lower for the tertiary schooling group. Mexico is an outlier among the countries, with evidence of an increasing prevalence of smoking with higher levels of schooling.

There are two main patterns in the relationship between schooling and BMI (Fig. 7). In Costa Rica, Mexico, and South Korea, levels of BMI are comparable across all four schooling groups. In China, Indonesia, and South Africa, mean BMI increases across levels of schooling with the highest levels among those with tertiary schooling.

4. Discussion

Across six MICs, only adults with tertiary schooling have a consistent adult mortality advantage compared to those with no schooling. Importantly, this group represents only a small fraction of the population of each country under study. We do not find evidence that individuals with primary schooling have lower mortality compared to

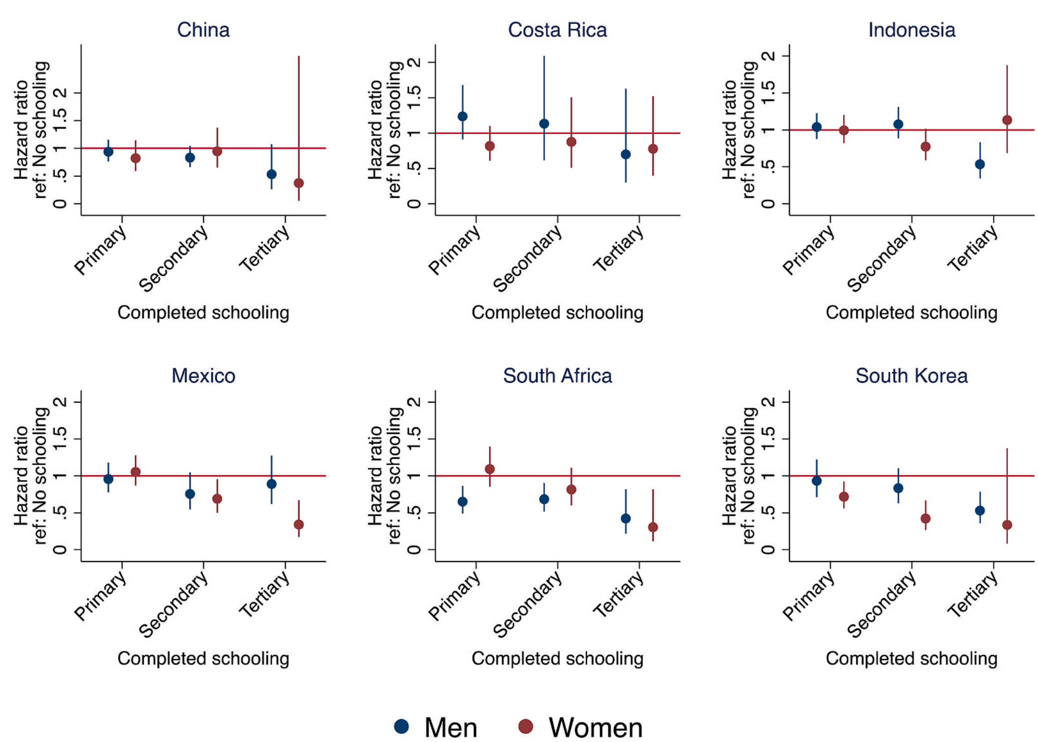

Fig. 4. Relationship between schooling and mortality separately by sex. [a]Results are presented as hazard ratios relative to individuals with no schooling. [b]Error bars represent 95% confidence intervals. [c]Estimates are from Cox Proportional Hazards models with controls for age (dummies with 5-year groups) estimated separately for men and women.

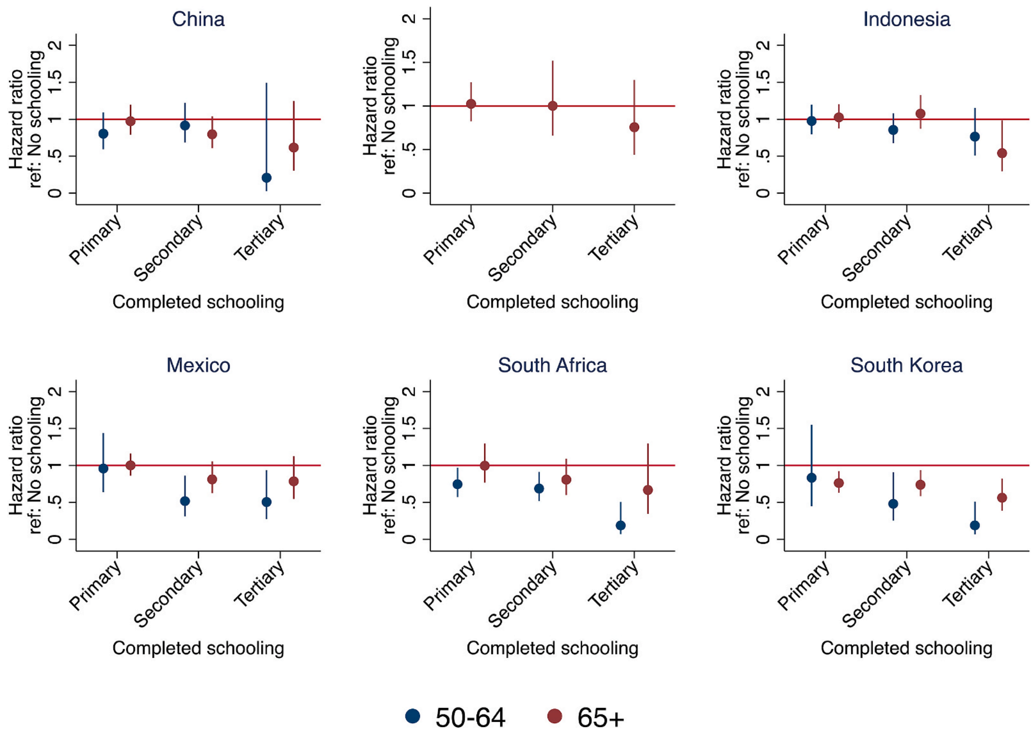

Fig. 5. Relationship between schooling and mortality separately by age groups. [a]Results are presented as hazard ratios relative to individuals with no schooling. [b]Error bars represent 95% confidence intervals. [c]Estimates are from Cox Proportional Hazards models with controls for age (dummies with 5-year groups) estimated separately for those between ages 50–64 and 65+. [d]Costa Rican data did not have individuals between the ages of 50 and 65.

individuals with no schooling in five of the six countries. The mortality advantage for individuals with secondary schooling is mixed, with evidence of lower mortality relative to those with no schooling in Mexico, South Africa, and South Korea, but not in China, Costa Rica, or Indonesia. These patterns are mostly consistent for both men and women; however, among Indonesian women and Mexican men, there is some evidence that even those with tertiary schooling do not have a distinct mortality advantage.

An important question is why we observe flat gradients for primary and secondary schooling. A recent literature has shown that the composition of individuals in the reference schooling category can have an influence on the magnitude of schooling gradients (Hendi, 2015). However, we find similar results when using a relative measure of schooling and when we combine the bottom two groups to ensure a comparably sized reference group across countries. These results suggest that the selectivity of the no schooling group is unlikely to be driving our

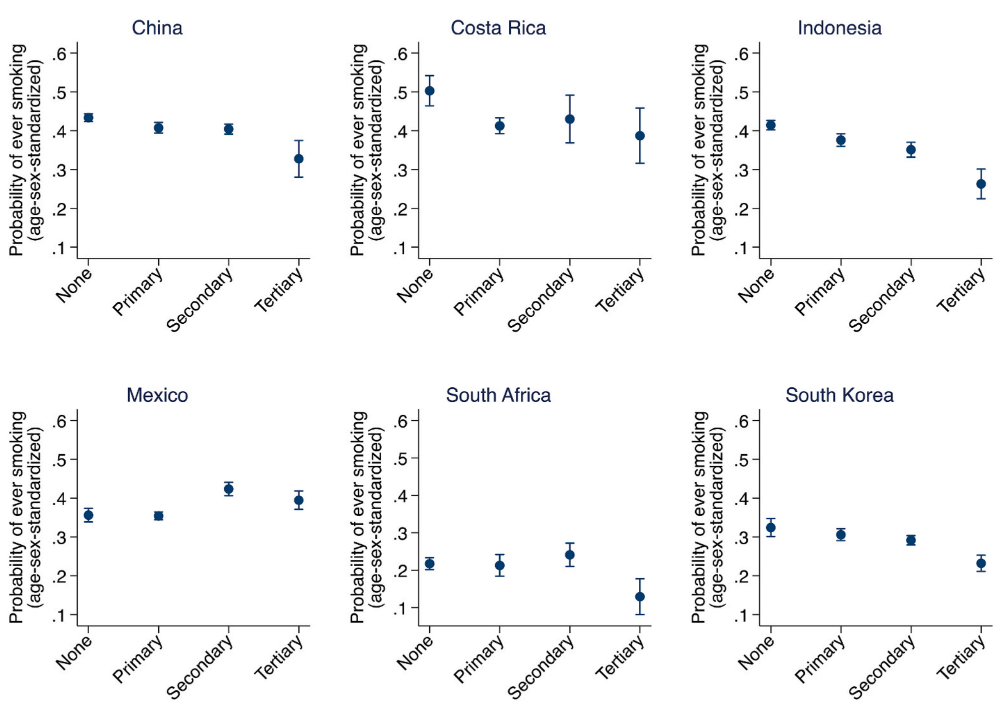

Fig. 6. Age-sex-standardized prevalence of ever smoking by schooling groups. [a]Error bars represent 95% confidence intervals.

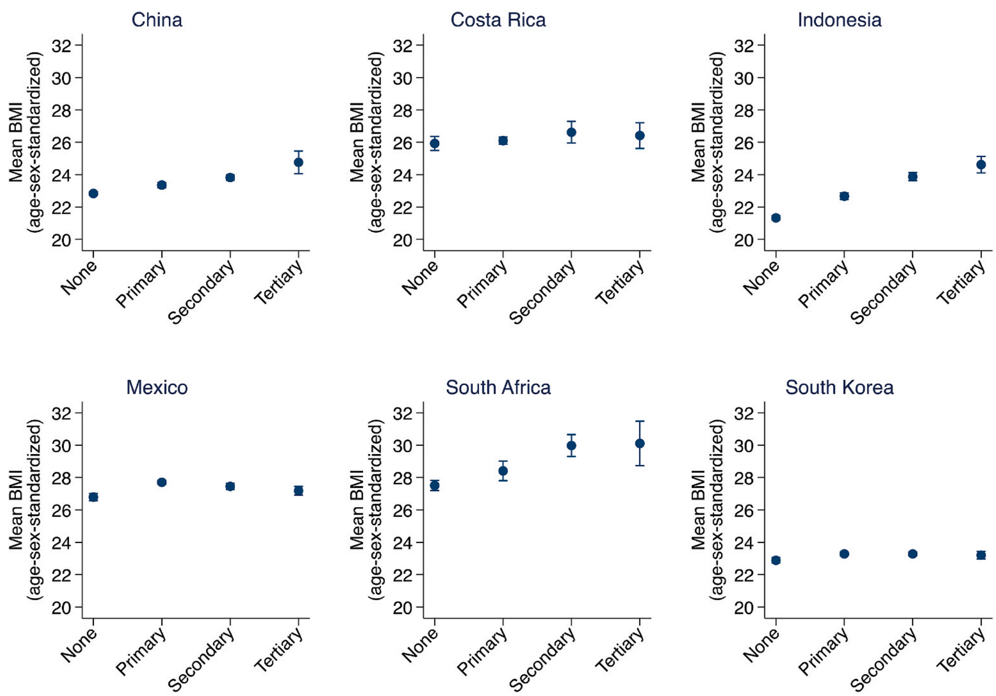

Fig. 7. Age-sex-standardized mean of body mass index by schooling groups. [a]Error bars represent 95% confidence intervals.

results. One commonly raised hypothesis is that improved social safety nets may lead to flatter gradients. This explanation, however, has not received empirical support in Europe, where Northern European countries have more pronounced gradients compared to Southern European countries despite having more developed and generous safety nets (Mackenbach et al., 2008; Maskileyson, 2014). This explanation is even less likely to explain our results since most of the countries in our data do not have developed social safety nets. Economic theories argue that part of the relationship between schooling and mortality is driven through the wage returns to schooling, finding for example, evidence of steeper gradients for cohort graduating into recessions, suggesting that higher schooling is insulating against a poor job market (Cutler et al., 2015). However, recent evidence finds similarly large returns to schooling in LMICs as in many HICs, suggesting that poor schooling-returns are unlikely to explain the flat gradients at the initial part of the schooling distribution (Psacharopoulos & Patrinos, 2018).

The education gradient seen in HICs is in part attributed to higher levels of poor health-related behaviors, such as smoking and unhealthy alcohol consumption, among individuals with lower levels of schooling (Martikainen et al., 2013; Meara et al., 2008). Among our countries, however, we find levels of smoking and BMI are not strongly patterned by schooling, and in some countries, unhealthy levels of risk factors are actually higher among the more educated groups. The generally poor quality of healthcare in MICs (Kruk et al., 2018), may also mean that only the most educated have access to a level of healthcare that meaningfully affects their longevity. Beyond the direct causal effect of schooling on health, schooling in HICs is often a strong indicator of social class and socioeconomic status (SES) (Phelan et al., 2010). This implies that individuals with more schooling are often advantaged in other dimensions, such as through improved parental resources and better neighborhood and environmental conditions (Cutler & Lleras-Muney, 2010). In countries with recent expansions in secondary and tertiary education, like those in our study, schooling may not be a strong indicator of social class and thus may not sort individuals into those with general lifecourse advantages and those without. Individuals in our sample were all born during times of comparatively high infant and child mortality (UN Inter-agency Group for Child Mortality Estimation, 2019). Therefore, the weak gradients we observe may be the result of selective mortality, whereby only healthier individuals survived to the older ages and thus the older age population is less heterogeneous with respect to mortality risks.

A related question is what explains why gradients are different across the six countries? Unfortunately, to our knowledge there are few studies exploring reasons behind the health gradient in LMICs. In contrast, several studies have sought to explain international variation in health gradients in HICs (Avendano et al., 2009; Chauvel & Leist, 2015; Dow & Rehkopf, 2010; Mackenbach et al., 2008; Maskileyson, 2014; Semyonov et al., 2013). The first major finding from these studies is while health behaviors such as smoking, alcohol use, and obesity are patterned strongly by schooling in some countries, this association is not consistent across countries and only smoking primarily explains a small amount of within or across country differences in the health gradient (Avendano et al., 2009; D.; Cutler & Lleras-Muney, 2012; Dow & Rehkopf, 2010). We find similar results. Gradients in BMI are either flat or actually increase with schooling. We do find some evidence that smoking is more pronounced among those with tertiary schooling and thus may explain a portion of the within-country gradients for some countries; however, the patterns of smoking are unlikely to explain differences in mortality gradients across countries. Studies on HICs have also found that while national level income, health inequality, and the level of meritocracy (proxied by the Human Development Index [HDI]) are related to cross-country differences in overall levels of population health, they are not associated with differences in the magnitude of the gradient across countries (Chauvel & Leist, 2015; Semyonov et al., 2013). We observe a similar pattern in our data; for example, we find evidence of strong gradients in South Korea, the country with the highest HDI in our study, but flat gradients for Costa Rica, the country with the next highest HDI. Similarly, we observe similarly sized gradients in Mexico and South Africa even though the two countries have drastically different levels of life expectancy at birth, gross domestic product per capita, and levels of income inequality. One important area of future research will be to collect richer context-specific data to better understand when gradients emerge and why they differ across contexts.

Our results are consistent with the broader literature on (SES) and mortality in LMICs despite study differences in the exact measures of SES and approach to estimating gradients. Luo and Xie (2014), use a parametric survival approach to study schooling gradients among the very old in China - ultimately concluding that schooling gradients are moderate and mostly only present for the highest school group (Luo & Xie, 2014). Rosero-Bixby and Dow (2009) use data from CRELES in Costa Rica to study the relationship between several measures of SES (one of which is schooling) and mortality using parametric survival models. Similar to our findings, they find that gradients in SES are flat and, in some cases, may actually show higher mortality among the more advantaged (Rosero-Bixby & Dow, 2009). Sudharsanan (2019) examines gradients in period life expectancy in Indonesia using two different measures of SES (Sudharsanan, 2019). Similar to our results, he finds evidence of inconsistent and often flat gradients. Houle et al. (2014) use data from a demographic surveillance site in rural South Africa with a discrete time survival approach similar to ours and find small but not statistically distinct gradients across a composite SES quintile measure (Houle et al., 2014). Importantly, our results differed slightly with existing literature in Mexico. Rosero-Bixby (2018) converts survival time estimates into life expectancies, finding evidence of a gradient for Mexican men but not women (Rosero-Bixby, 2018). Further investigation is needed to determine why their results differ from the ones presented here.

Our study has some important limitations. First, while we provide evidence on the size of schooling gradients, our results do not speak to potential explanations for these differences. Second, there is some potential for bias in the schooling gradient estimates due to selective loss to follow-up across survey waves. However, the magnitude of loss to followup was less than 10% for each survey and we find that losstofollow up is correlated with better self-rated health and higher levels of schooling, suggesting that those lost to followup may actually have lower mortality than those in the data (Appendix V). Under this scenario, our estimated gradients would actually be flatter. Indeed, in sensitivity analyses (Appendix VI), we find that even if none of the individuals that were lost died between waves, our primary conclusions remain unchanged. However, since mortality reports are from other household-members in follow-up waves, if families of lower schooling individuals were more likely to incorrectly report the mortality status of survey respondents, the results may be biased by an artificially low mortality rate among the lower schooling groups, giving the impression of a weaker schooling gradient. Both these two limitations could be overcome through mortality information drawn from national death registries. Unfortunately, to the best of our knowledge, only Costa Rica and South Korea collect data that can be linked to national death registries. Our results are similar to the studies that take advantage of these registry linkages. For example, these studies also find no gradient in Costa Rica and a pronounced gradient in South Korea (Khang & Kim, 2005; Rosero-Bixby & Dow, 2009). Lastly, our data are only for six specific countries and may not generalize to a broad set of MICs. Despite these limitations, our study is one of the first to examine schooling gradients in adult mortality across several MICs using a consistent analytical approach and harmonized nationally-representative data sources.

Overall, we find that tertiary education is associated with lower mortality in five of the six countries. However, the schooling gradient among individuals with less than tertiary schooling is less clear with evidence of differences in some countries but not others. These differences may reflect truly flat gradients or limitations from survey-based measurements of mortality, such as low statistical power and potential measurement error. An important open question is whether inequalities will emerge as MICs continue to develop, or if these countries are on a fundamentally different adult mortality trajectory. Our results highlight that adult mortality gradients are far from an inevitability and are not necessarily found in all populations. Understanding what factors give rise to inequalities in adult mortality and what can be done to minimize gradients while still ensuring continued mortality improvements in MICs is a crucial focus for research and policy.

Ethics statement

This study was exempt from IRB review because it used publicly available de-identified secondary data.

CRediT authorship contribution statement

Nikkil Sudharsanan: Conceptualization, Formal analysis, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration. **Yuan Zhang:** Formal analysis, Data curation. **Collin F. Payne:** Conceptualization, Writing - review & editing. **William Dow:** Conceptualization, Writing - review & editing, Supervision. **Eileen Crimmins:** Conceptualization, Writing - review & editing, Supervision.

Declaration of competing interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2020.100649.

Appendices.

Appendix I
Sampling information for each survey.

Survey name	Years of data collection used in study	Eligibility criteria	Sample design	Mortality assessment
China Health and Retirement Longitudinal Study	2011, 2013, 2014, 2015	Households with member aged 45+	*First stage*: random sample of counties *Second stage*: random sample of PSUs *Third stage*: random sample of HH's *Interviews:* a randomly selected individual aged 45+ and their spouse	Household or family-member reported date of death at each follow-up wave.
Costa Rican Longevity and Healthy Aging	2005, 2007, 2009	Individuals aged 55+	*First stage*: random sample of individuals from 2000 Census of Population *Strata*: 5-year age groups *Interviews*: sampled individuals	Household-member reported date of death at each follow-up wave.

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Appendix I (*continued*)

Survey name	Years of data collection used in study	Eligibility criteria	Sample design	Mortality assessment
Indonesian Family Life Survey	2007, 2014/15	All households	*First stage*: random sample of census enumeration areas *Second stage*: random sample of HH's *Interviews*: HH head and spouse, two randomly selected children, a randomly selected individual age 50+ and their spouse.	Household-member reported date of death at each follow-up wave.
Mexican Health and Aging Study	2012, 2015	Individuals aged 50+ and their spouse	*First stage*: random sample of PSUs *Second stage*: random sample of HHs *Interviews*: randomly selected individual aged 50–60 along with their spouse. *Strata*: State, urban/rural (In 2012, addition individuals aged 50–60 were randomly sampled directly from National Occupation and Employment Survey)	Household-member reported date of death at each follow-up wave.
National Income Dynamics Study (South Africa)	2008, 2010/11, 2012, 2014/15	All households	*First stage:* random sample of PSUs from Stats SA Master Sample *Second stage*: random sample of HHs *Interviews*: all HH members *Strata*: district councils	Mortality status was assessed at the follow-up wave of data collection without an exact date of death.
Korean Longitudinal Study of Aging	2006, 2008, 2010, 2012	Individuals aged 45+	*First* stage: random sample of enumeration districts *Second* stage: random sample of HH's with member aged 45+ *Interview:* *Strata:* urban/rural, apartment/house	Household-member reported date of death at each follow-up wave.

Appendix II
Classification of country-specific schooling categories.

Survey name	None	Primary	Secondary	Tertiary
China Health and Retirement Longitudinal Study	• No formal education • Did not finish primary school • Sishu	• Elementary school	• Middle school • High school • Vocational school	• Two/three year college/Associate degree • Four year college/Bachelor's degree • Post-graduated (Master/Phd)
Costa Rican Longevity and Healthy Aging	• None	• Elementary	• Secondary, academic • Secondary, technical	• Para-university • Higher education
Indonesian Family Life Survey	• None	• Elementary school • Adult education A • Islamic Elementary school	• Junior high - general • Junior high - vocational • Senior high - general • Senior high - vocational • Adult education C • Islamic Junior high school • Islamic Senior high school	• Open University • College D1, D2, D3 • University S1 • University S2 • University S3
Mexican Health and Aging Study	• None	• Primary	• Secondary • Technical or commercial • Preparatory of high school	• Basic teaching school • College • Graduate
National Income Dynamics Study (South Africa)	• No schooling • Grades R-6	• Grades 7-8	• Grade 9-12 • NTC 1 • NTC 2 • NTC 3 • Certificate with less than Grade 12 • Diploma with less than Grade 12 • Certificate with Grade 12	• Diploma with Grade 12 • Bachelor's degree - Level 4 • Bachelor's degree and Diploma • Honours degree • Higher degree (Masters/ Doctorate)
Korean Longitudinal Study of Aging	• No education (illiterate) • No education (reading)	• Elementary school	• Middle school • High school	• Two-year grad • College grad • Post college (Master) • Post college (PhD)

Appendix III
Age and death distributions

Age and death distribution, China				
Age group	Men		Women	
	Individuals	Deaths	Individuals	Deaths
50	1137	34	1200	17
55	1529	62	1626	42
60	1281	86	1234	53
65	844	84	831	43
70	608	91	551	59

(*continued on next page*)

Appendix III (*continued*)

Age and death distribution, China				
Age group	Men		Women	
	Individuals	Deaths	Individuals	Deaths
75	374	99	381	90
80	160	62	212	70
85	57	34	109	53
Total	5990	552	6144	427

Age and death distribution, Costa Rica				
Age group	Men		Women	
	Individuals	Deaths	Individuals	Deaths
50	0	0	0	0
55	0	0	0	0
60	142	5	183	8
65	205	16	249	19
70	207	28	227	20
75	216	27	217	30
80	171	43	224	54
85	244	122	316	132
Total	1185	241	1416	263

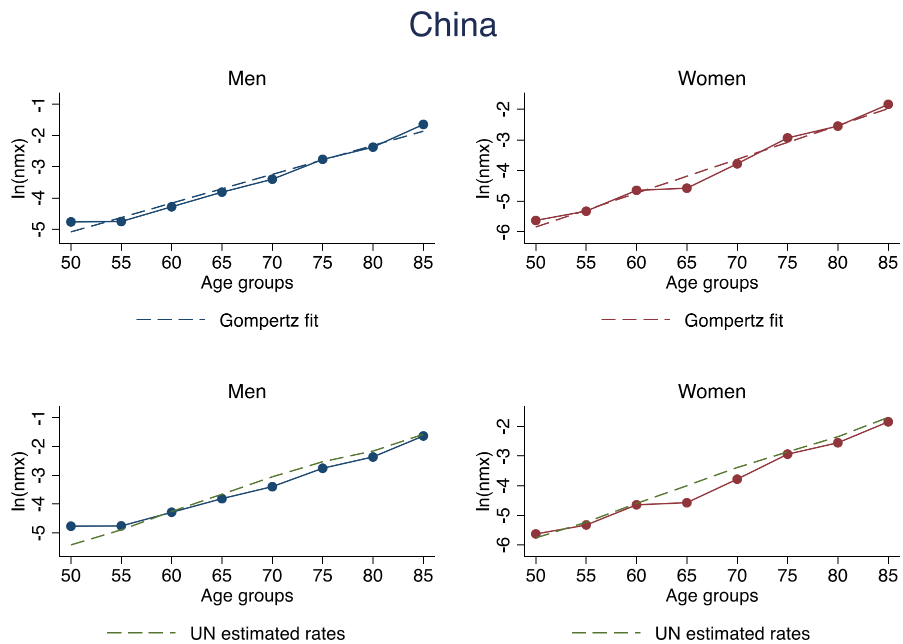
Age and death distribution, Indonesia				
	Men		Women	
Age group	Individuals	Deaths	Individuals	Deaths
50	888	100	1001	68
55	690	89	715	84
60	485	103	583	98
65	479	143	580	162
70	291	133	372	127
75	173	87	254	125
80	119	72	166	92
85	81	54	92	69
Total	3206	781	3763	825

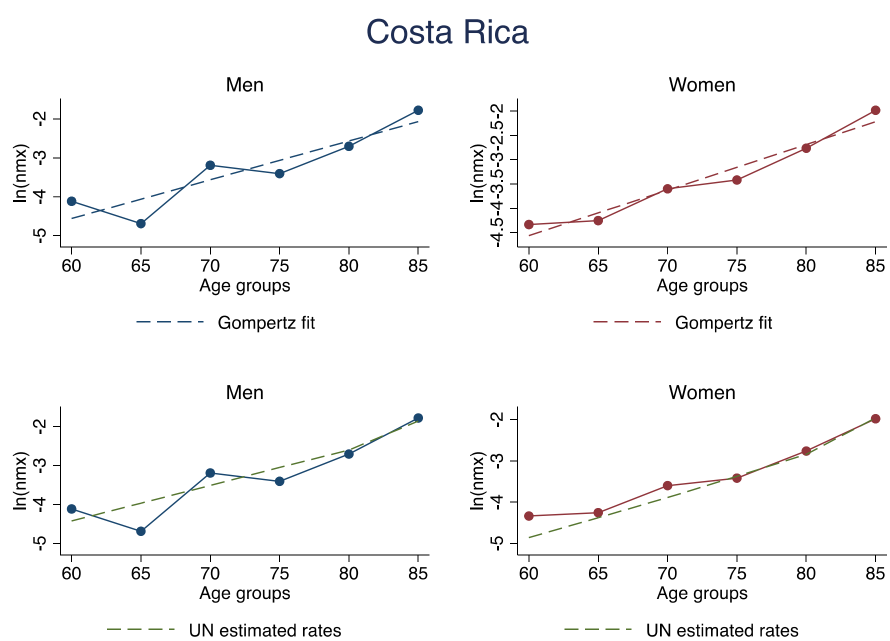
Age and death distribution, Mexico				
Age group	Men		Women	
	Individuals	Deaths	Individuals	Deaths
50	871	7	1273	15
55	811	23	1460	30
60	1135	65	1396	56
65	1162	75	1285	64
70	791	71	964	76
75	595	98	710	84
80	372	79	461	93
85	259	98	339	127
Total	5996	516	7888	545

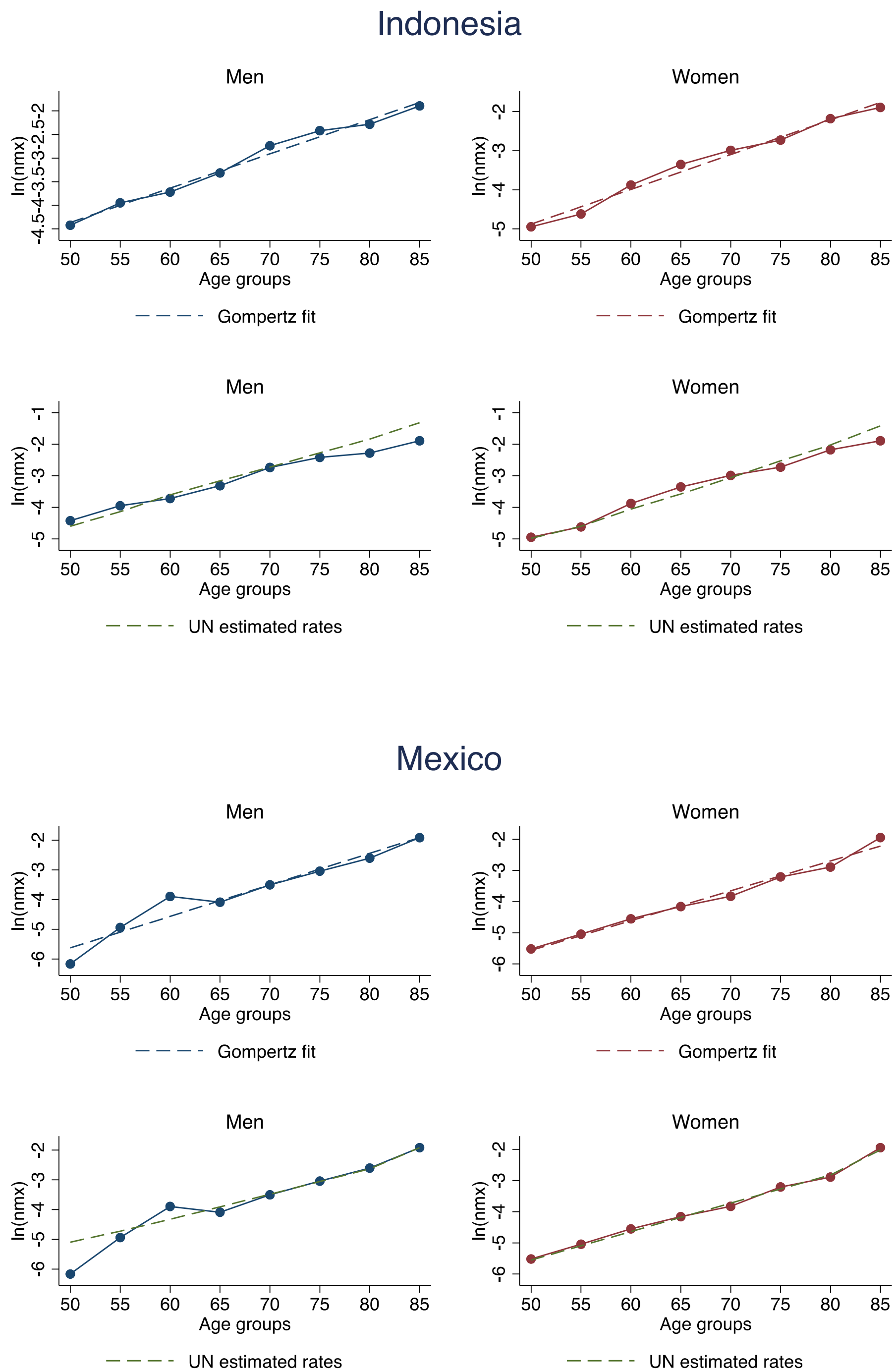
Age and death distribution, South Africa				
Age group	Men		Women	
	Individuals	Deaths	Individuals	Deaths
50	360	76	615	64
55	302	70	530	66
60	234	66	375	75
65	202	74	386	90
70	113	63	246	68
75	97	51	211	74
80	43	26	89	45
85	24	23	67	35
Total	1375	449	2519	517

Age and death distribution, South Korea				
Age group	Men		Women	
	Individuals	Deaths	Individuals	Deaths
50	600	22	738	9
55	583	27	679	11
60	580	39	697	18
65	621	84	737	44
70	472	77	576	52
75	285	81	461	85
80	139	65	243	74
85	59	36	145	80
Total	3339	431	4276	373

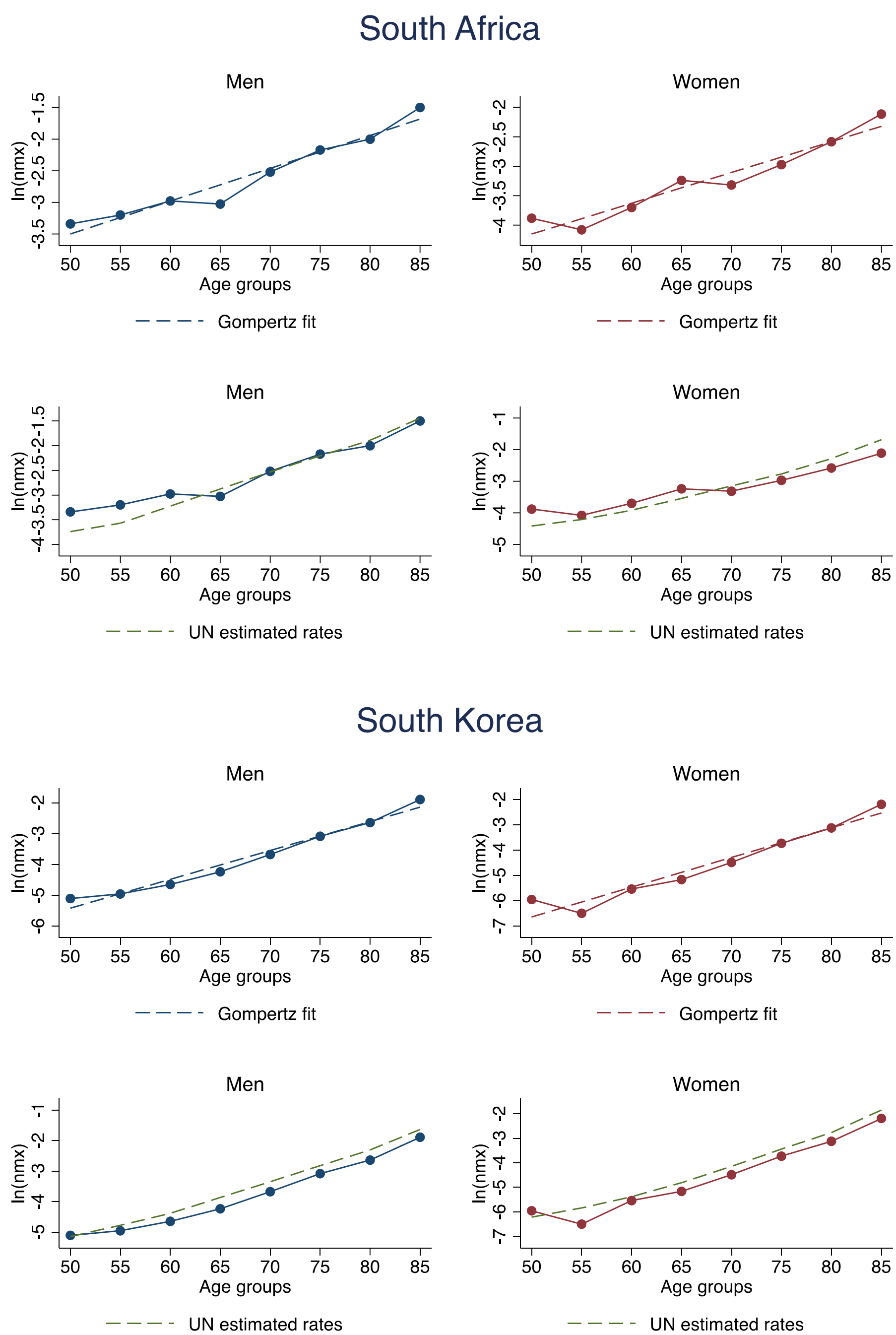
Appendix IV. Comparison of estimated age-specific mortality rates to a Gompertz fit and the estimates from the United Nations





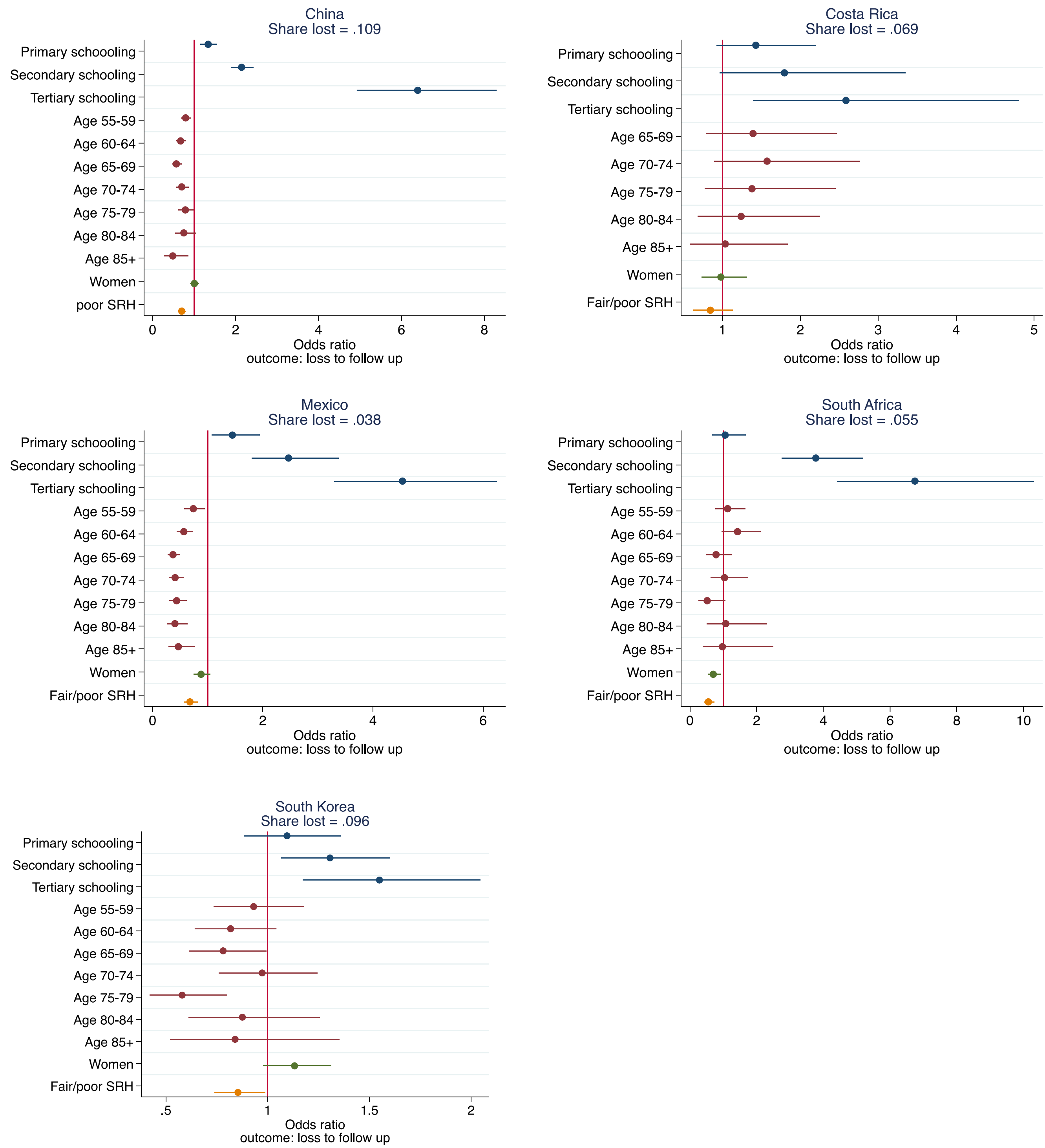

Indonesia
Men
Women
ln(nmx)
Age groups
Gompertz fit
UN estimated rates
Mexico
Men
Women
ln(nmx)
Age groups
Gompertz fit
UN estimated rates

. (*continued*).

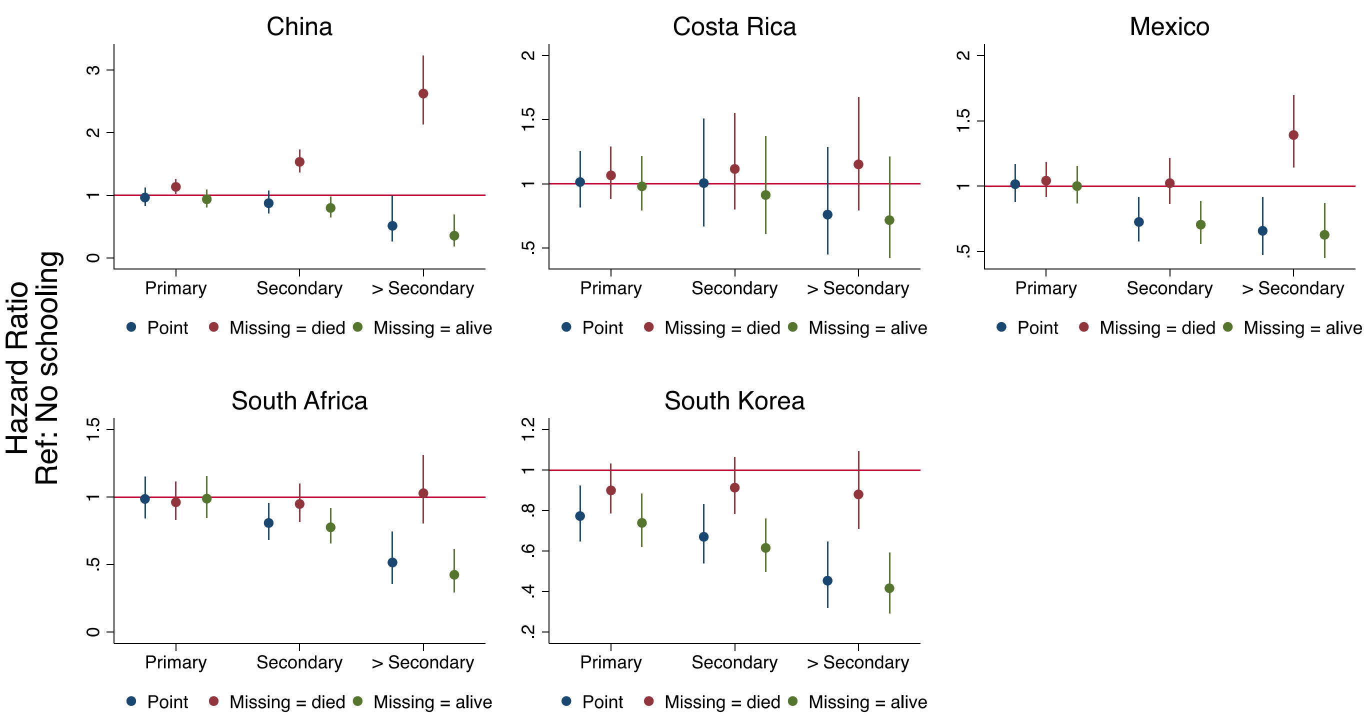

South Africa
Men
Women
ln(nmx)
Age groups
50 55 60 65 70 75 80 85
Gompertz fit
UN estimated rates
South Korea
Men
Women
ln(nmx)
Age groups
50 55 60 65 70 75 80 85
Gompertz fit
UN estimated rates

. (*continued*).

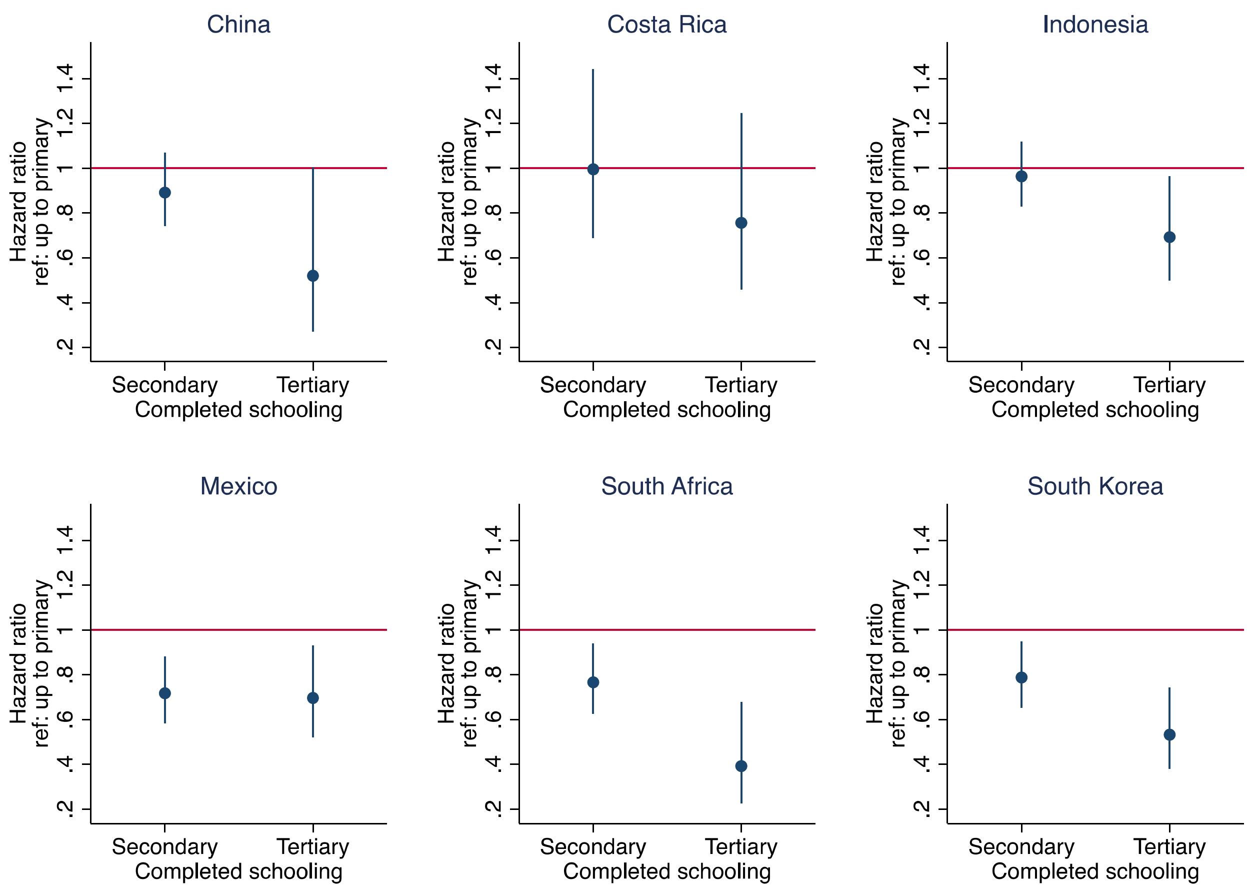
Appendix V. Predictors of loss to follow up across countries. The results for the following graphs come from separate regressions of loss to follow-up regressed on schooling, age, sex, and poor/fair self-rated health separately for each variable (four regressions for each country). The reference groups for schooling and age are no schooling and ages 50–55 (60–65 for Costa Rica)



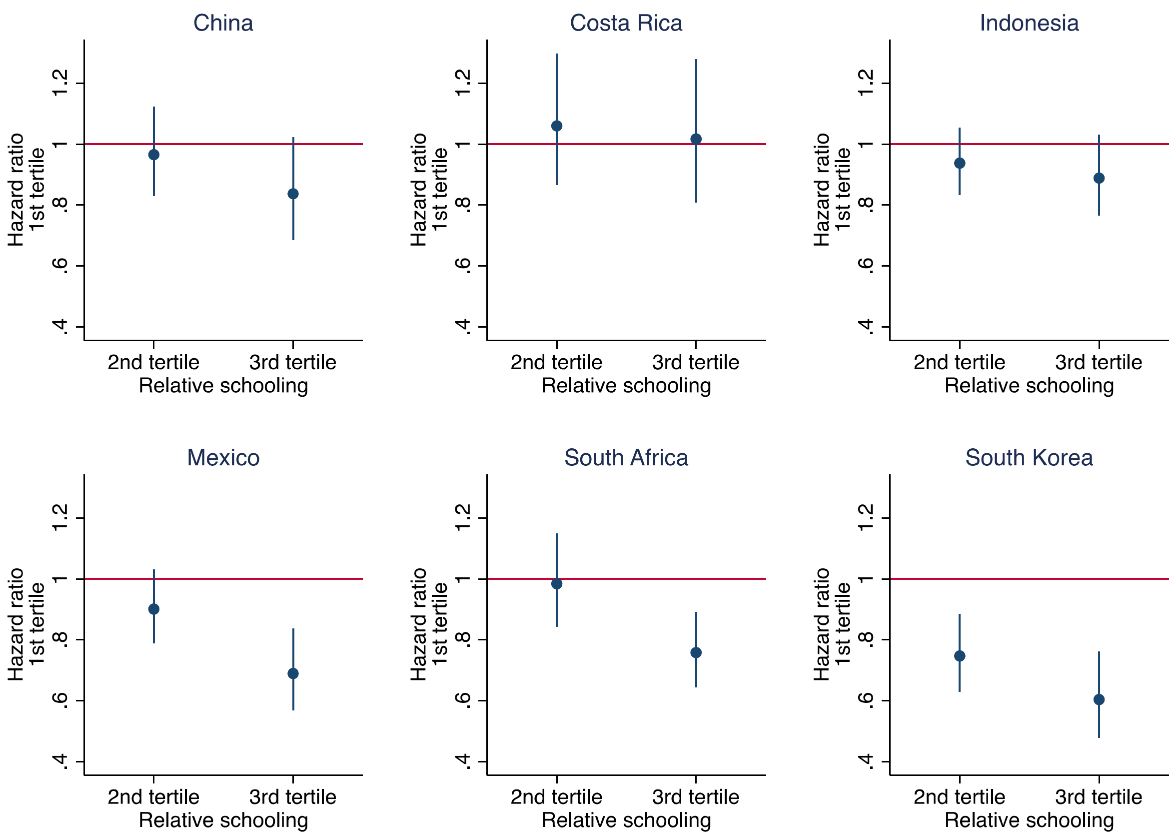
Appendix VI. Sensitivity analyses with loss to follow-up. For these analyses, we re-estimated the gradients assuming that all individuals that were lost to follow-up had died (the red series) or that all had survived (the green series)



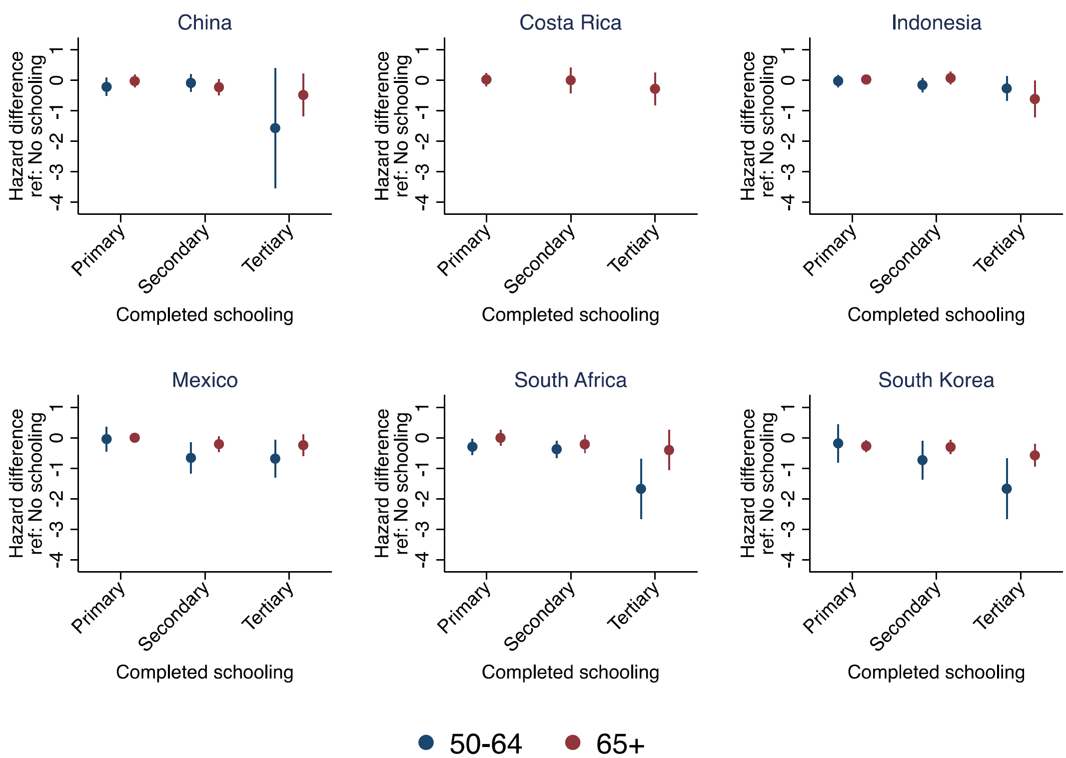
Appendix VII. Sensitivity analyses with alternative classifications of schooling. Relationship between schooling and mortality combining the none and primary schooling groups as the referent category



Relationship between schooling and adult mortality using approximate tertiles of years of schooling. Tertiles were approximate since the empirical distribution of schooling in countries could not be broken into exact thirds.



Appendix VIII. Relationship between schooling and mortality stratified by age on the hazard-difference scale



[a]Results are presented as hazard differences relative to individuals with no schooling.
[b]Error bars represent 95% confidence intervals.
[c]Estimates are from Cox Proportional Hazards models with controls for age (dummies with 5-year groups) estimated separately for those between ages 50–64 and 65+.
[d]Costa Rican data did not have individuals between the ages of 50 and 65.

Appendix IX
Comparison of tertiary schooling proportions with the Barro-Lee database

	Men		Women	
	Our estimate	Barro-Lee	Our estimate	Barro-Lee
China	2%	2%	1%	1%
Costa Rica	6%	11%	5%	8%
Indonesia	6%	3%	3%	1%
Mexico	13%	13%	7%	7%
South Africa	5%	1%	3%	0%
South Korea	15%	20%	3%	5%

Notes: The Barro-Lee estimates (1) are presented by 5-year age groups. In order to facilitate comparison with our results, we multiplied the Barro-Lee age-specific estimates for ages 50 and above by the corresponding population share in each country and summed across age groups to generate an average schooling estimate for the 50+ population (this same process was done for just the 60+ population in Costa Rica).

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