THE CHANGING RELATIONSHIP BETWEEN BODYWEIGHT AND LONGEVITY IN HIGH- AND LOW-INCOME COUNTRIES

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ABSTRACT

Standard measures of bodyweight (overweight and obese, for example) fail to reflect technological progress over time - and in particular, recent progress disproportionately promoting longevity at higher bodyweights (and differences in access to it). This paper builds on the pioneering work of Hans Waaler (Waaler, 1984) and Robert Fogel (Fogel, 1994) to empirically estimate how technological progress, and differential access to it, have fundamentally transformed the relationship between body mass index (BMI) and longevity in high-, middle-, and low-income countries. Importantly, we show that the combined effect of technological progress and access to it across countries is so profound that the share of national populations above mortality-minimizing bodyweight is not clearly greater in countries with higher overweight and obesity rates (as traditionally defined) - and in fact, relative to current standards, a larger share of low-income countries' populations can be unhealthily heavy.

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Bodyweight has been rising around the world for centuries. Historically, innovation in agriculture has reduced the real price of calories (Ankli, 1980), fueling increases in human stature (Fogel, 1994; Fogel and Costa, 1997; Floud et al., 2011). Early gains in bodyweight reduced chronic malnutrition, promoting immune resilience and dramatically raising life expectancy in Western nations (Fogel and Costa, 1997; Sen, 1982; Drèze and Sen, 2013). However, the continued rise in bodyweight - and obesity - has more recently been treated with alarm because of accompanying chronic disease morbidity and mortality (Fontaine et al., 2003; Yach et al., 2006; Popkin and Gordon-Larsen, 2004; Ebbeling et al., 2002). In lower-income countries today, which confront a simultaneous "double burden" of undernutrition and obesity, rising bodyweight is a mixed blessing, helping some and harming others (Shrimpton and Rokx, 2012; Strauss and Thomas, 1998; Biswas et al., 2020). Approximately two billion people globally are overweight or obese, a number projected to rise (Roberto et al., 2015).

Clinically, whether a particular bodyweight is healthy is a complex question determined by more than just weight and height. For example, body mass index (BMI, or the ratio of weight in kilograms to height in meters squared) does not discriminate between fat and muscle mass (Heitmann et al., 2000; Ortega et al., 2016). Nonetheless, at the population level, BMI is a widely used summary statistic. According to the World Health Organization, for adults, a BMI less than 18.5 indicates underweight, between 18.5 and 25 indicates normal weight, between 25 and 30 indicates overweight, and 30 or above indicates obesity (WHO, 1995). Population increases in BMI above 25 or 30 are therefore generally considered markers of deteriorating health (Di Angelantonio et al., 2016).

There are several important problems with this approach. First, these BMI thresholds are somewhat arbitrarily defined. Second, they do not reflect genotypic differences in body fat distribution (WHO, 2000; Mehta et al., 2013; Nakagami et al., 2003; Bodicoat et al., 2014). Third, and importantly, health technology is changing in response to population anthropometrics in ways that promote longevity among those considered overweight or obese. Several studies now find that BMI in the overweight range is not associated with increased mortality risk (Flegal et al., 2013; Chen et al., 2019; Gu et al., 2006), particularly among the elderly (Winter et al., 2014; Berraho et al., 2010).

A superior approach to relying on fixed thresholds across countries and over time is to use iso-mortality curves - pioneered by Hans Waaler (Waaler, 1984) and promoted by Nobel laureate Robert Fogel (Fogel, 1994; Fogel and Costa, 1997) - as a tool for understanding the changing population health consequences of anthropometric status. Estimated using detailed data on both anthropometric status and mortality risk, iso-mortality curves - or Waaler surfaces - relate mortality to height and weight. They do not impose bright-line thresholds on the joint distribution of height and weight. Moreover, they can be estimated separately for different populations at different points in time, and changes in their shapes and locations can generally be interpreted as reflecting technological progress and access to health technologies, moderating the relationship between anthropometric status and longevity.

In this paper, we estimate new iso-mortality Waaler surfaces for three different contemporary environments: the United States (a high-income country), Mexico (a middle-income country), and Indonesia (a lower-income country) using detailed individual-level longitudinal data. These countries represent different technological regimes, broadly defined, for longevity at different heights and weights - and varying access to health technology. They also provide an update to Fogel's (1994) estimates (obtained using a sample of 50-64 year-old Norwegians observed between 1963 and 1975) with data reflecting technological progress in recent decades that has disproportionately focused on obesity-related chronic diseases (Bhattacharya and Packalen, 2011). The data requirements for this approach are stringent; few representative surveys measure individual anthropometric characteristics and follow the same individuals over time, recording subsequent deaths. We analyze data from the Health and Retirement Study (HRS) in the U.S., the Mexican Health and Aging Study (MHAS) in Mexico, and the Indonesian Family Life Survey (IFLS) in Indonesia. We standardize the construction of our longitudinal, individual-level samples across these surveys over the period 2002 to 2016, focusing on adult populations at ages in which chronic diseases commonly emerge (ages 50-79). Bodyweight and height are objectively measured in the IFLS, while in the HRS and MHAS they are self-reported [1].

Within these Waaler surfaces, a minimum risk curve traces the bodyweight that minimizes mortality risk at each height, with mortality risk increasing at bodyweights both to the left and right of the curve. Supplement Figure B1 first shows how average combinations of weight and height at middle and older ages (50-79) have changed in recent decades (from 1995 to 2014) relative to the original minimum risk curve estimated by Waaler (1984) and Fogel (1994). In the United States, average height has remained constant over time, while average bodyweight has increased. Thus, the U.S. was already to the right of Fogel's minimum risk curve in 1995, rising to a point further above it in 2014. By contrast, Mexico's and Indonesia's height and bodyweight have both risen steadily over the same period, moving Mexico above Fogel's minimum risk curve and Indonesia towards it. However, these national averages mask underlying heterogeneity

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[1] The objective measurement of height and weight in HRS started in 2006 for a subsample of the individuals. To maintain comparability across waves we use self-reported measures throughout the entire analysis period.

in their distribution, which we consider below.

Figure 1 presents age-adjusted Waaler surfaces for the United States, Mexico, and Indonesia, estimated separately for men and women in each country using our samples of contemporary data. The colored curves represent level sets of mortality risk, spaced in equal increments/decrements of absolute risk. Each panel also shows a corresponding minimum risk curve. Reflecting both technological differences and varying access to health technology, the location and shape of these Waaler surfaces and minimum risk curves differ considerably across countries (and between women and men). Arguably the most striking difference is between the Indonesian Waaler surfaces and those for the U.S. and Mexico. The Indonesian minimum risk curve reflects an absolute mortality risk above those for the U.S. and Mexico - and at all heights, the mortality risk for Indonesian men and women is minimized at substantially lower bodyweights.

Figure 2 shows the minimum risk curves corresponding to the Waaler surfaces in Figure 1 together with Fogel's original minimum risk curve. For a given height, the weight that minimizes mortality risk is lowest in Indonesia for both men and women. The corresponding values are substantially higher in Mexico and higher yet in the U.S. For example, for a 1.83 meter (approximately 6 feet) tall male, the minimum mortality weights are 64 kg (in Indonesia), 89 kg (in Mexico), and 96 kg (in the U.S.), corresponding to BMIs of 19.1, 26.6, and 28.7, respectively. These differences across countries are less pronounced for women - for example, for a 1.73 meter (approximately 5 feet 7 inch) tall female, the minimum mortality weights are 69 kg, 76 kg, and 80 kg, with corresponding BMIs of 23.1, 25.4, and 26.7, respectively. Notably, relative to a BMI of 25 (the WHO threshold for overweight), these minimum risk bodyweights are consistently lower in Indonesia and considerably higher in Mexico and the U.S.

We next analyze the distribution of anthropometric status in these three populations with respect to our estimates of their minimum risk curves. Figure 3 shows a heat map of the joint distributions of height and weight, separately for men and women, in each country using 5x5 unit cells (in cm of height and kg of weight) together with the corresponding minimum risk curves. The figure also shows the implied number of averted deaths over a 4-year horizon if all individuals in each population were to move to her/his minimum risk bodyweight (holding height constant). These averted deaths, weighted to obtain implied national totals, are shown to the left of the minimum risk curve for those gaining weight and to the curve's right for those losing weight.

For each country, we then compute ratios of the share of each national population above mortality-minimizing bodyweight to the share of each national population considered overweight by contemporary (WHO) standards (BMI>25). If contemporary standards defining unhealthily high bodyweights matched bodyweights above mortality-minimizing levels, these ratios would be 100% for each country. Instead, we find them to be 52.6% in the United States, 56.8% in Mexico, and 151.4% in Indonesia.[2] Strikingly, these ratios suggest that technological progress promoting longevity at higher bodyweights - and access to health technology - vary so profoundly across countries that, relative to current international standards, unhealthily high adult bodyweight is *underestimated* in Indonesia (a country with a relatively low overweight/obesity rate: 17 and 4 percent) and *overestimated* in the U.S. and Mexico (countries with relatively high overweight/obesity rates: 41 percent/29 percent and 43 percent/21 percent, respectively).

Our study has at least four limitations. First, our estimates rely on the correlation

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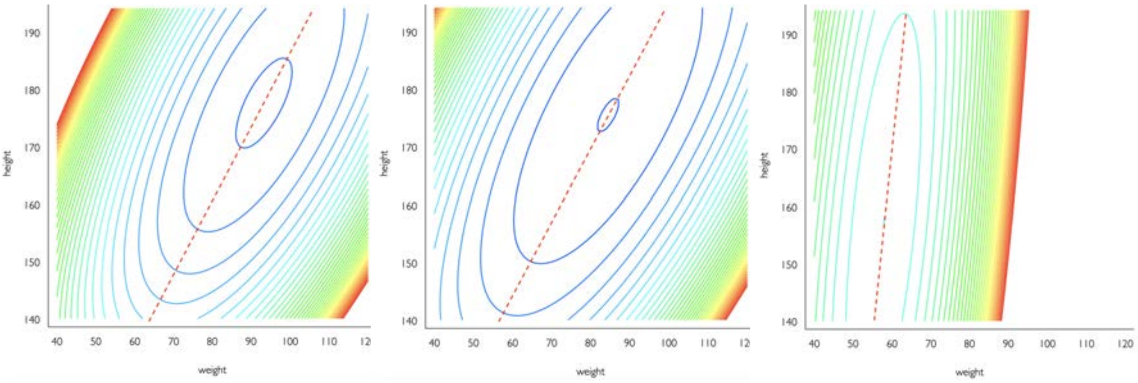
[2] The shares are computed as ratios of the total number of individuals (men and women aged 50-79) whose weight is greater than the optimum for their height as indicated by our Waaler minimum mortality curve (33,608,854 individuals for the U.S., 7,356,378 for Mexico and 12,361,973 for Indonesia) over the total number of individuals who are overweight or obese (63,850,227 for the U.S., 12,951,129 for Mexico and 8,186,011 for Indonesia).

between anthropometric status and mortality risk over the subsequent four years. Chronic diseases at the end of life are often associated with weight loss, which could contribute to a positive correlation between low bodyweight and mortality (Banack and Stokes, 2017; Kalantar-Zadeh et al., 2014). However, our use of a long lag between measured anthropometric status and mortality mitigates this limitation to some extent (because most weight loss approaching death occurs during the year that a patient dies). Second, our approach requires imputation of bodyweight for some individuals when there are long intervals between data collection. The longitudinal datasets that we use to track obesity – the Health and Retirement Study and its sister studies around the world – are the gold standard for individual-level panel data tracking health. In Indonesia and Mexico, however, there are longer intervals between waves than in the U.S., where data is collected every two years. To address this issue, we use standard interpolation methods to impute information between waves. Without imputation, our results are qualitatively similar, but noisier. Third, we attribute the observed differences in minimum risk curves across countries and over time to technological differences in detection and treatment along with differences in access to medical care. Our interpretation is consistent with the fact that treatment for diseases associated with obesity - such as heart disease - have improved over time (Ritchey et al., 2020). It is also consistent with the economics literature, which emphasizes technological change as a primary cause of bodyweight change over time (Lakdawalla et al., 2005; Lakdawalla and Philipson, 2009). However, there may be other explanations which we do not consider that contribute to our findings. Finally, data limitations prevent us from systematically examining important dimensions of morbidity correlated with anthropometric status.

Health-specific technological change over time has been dramatic. It has focused particularly on the emerging population health needs of wealthy countries over the past half-century, fundamentally transforming the relationship between bodyweight and longevity (Bhattacharya and Packalen, 2011). Moreover, access to these technologies varies greatly across higher- and lower-income countries, leading to substantial cross-country differences in the bodyweights that maximize health (or minimize mortality risk). Current bodyweight classification standards such as “overweight” (BMI 25-30) and “obese” (BMI 30+) do not reflect the moderating role of this technological progress or differences in access to health technology. Incorporating the changing role of technology is critical for understanding the population health implications of evolving anthropometric status around the world. Higher bodyweights, even conditional on height, do not unambiguously indicate a decline in population health status.

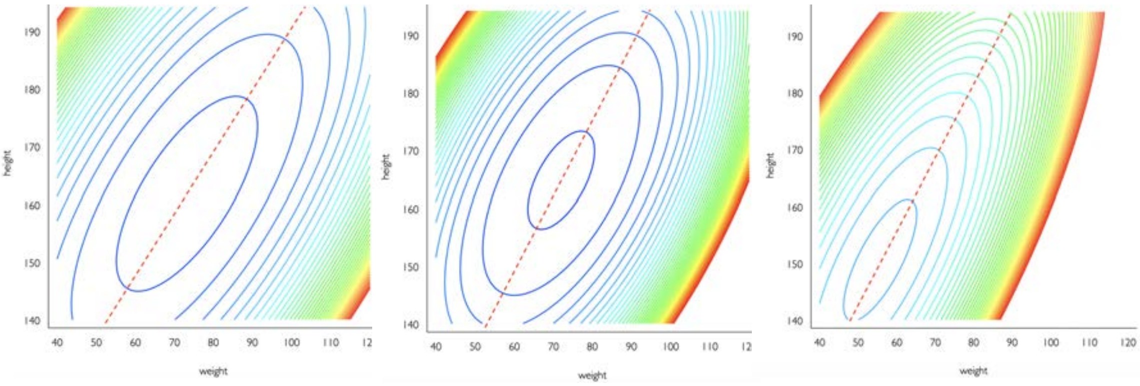
Figure 1: Waaler iso-mortality curves by gender and country

Men



USA Mexico Indonesia

Women



USA Mexico Indonesia

Notes: Our data sources are waves, conducted between 2002 and 2016, of the Health and Retirement Study (HRS) for the U.S., the Mexican Health and Aging Study (MHAS) for Mexico, and the Indonesian Family Life Survey (IFLS) for Indonesia. Each dataset is rectangularized between waves, with missing information on individual weight and height interpolated using nearest neighbourhood imputation. Individuals are followed until death or attrition from the sample. Weight and height data from the four years prior to when survival or death is observed are excluded (to account, in part, for weight loss approaching the time of death). The top and bottom percentile of the BMI distribution are trimmed from the MHAS and IFLS samples because the top and bottom percentiles of height and weight are top-/bottom-coded. Each panel is produced using estimates of probit response surfaces together with sampling weights, described in greater detail in Supplement C, and shows model predictions on a regular height/weight grid. The red dashed lines in each panel represent minimum mortality risk curves.

Figure 2: Waaler minimum mortality risk curve by gender and country

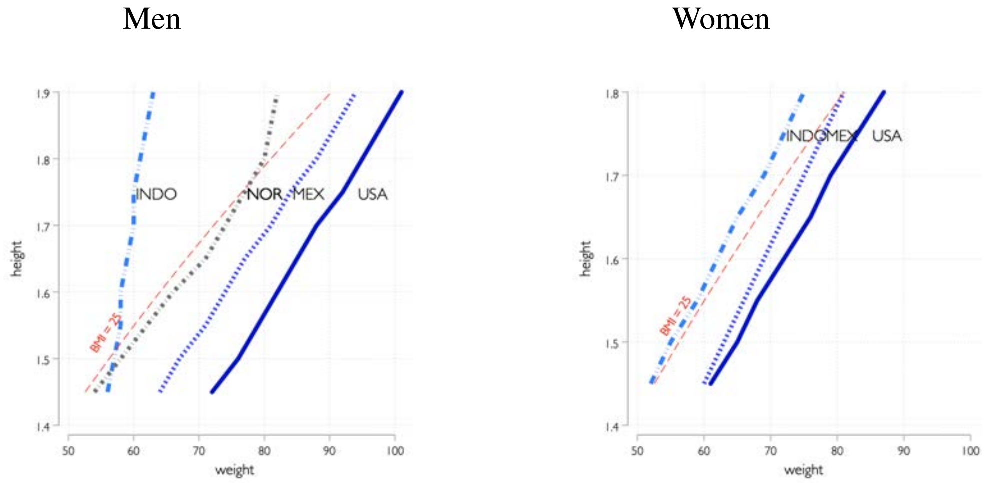


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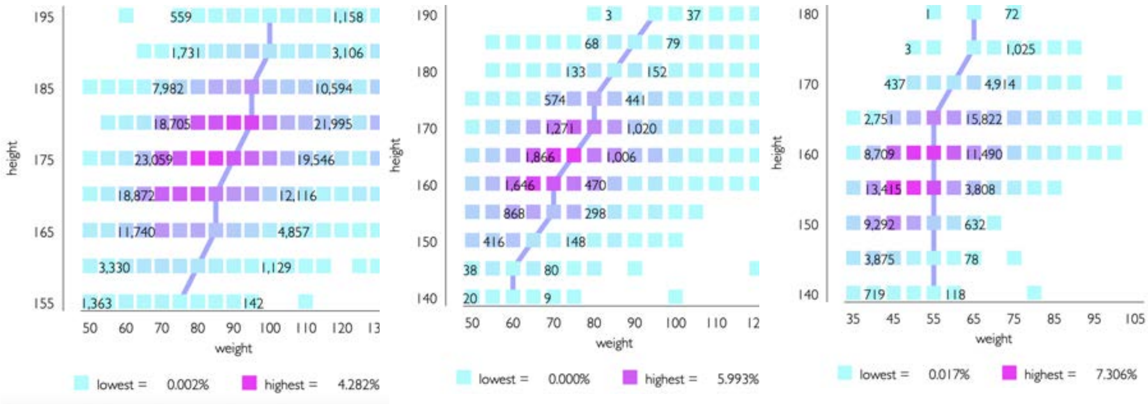
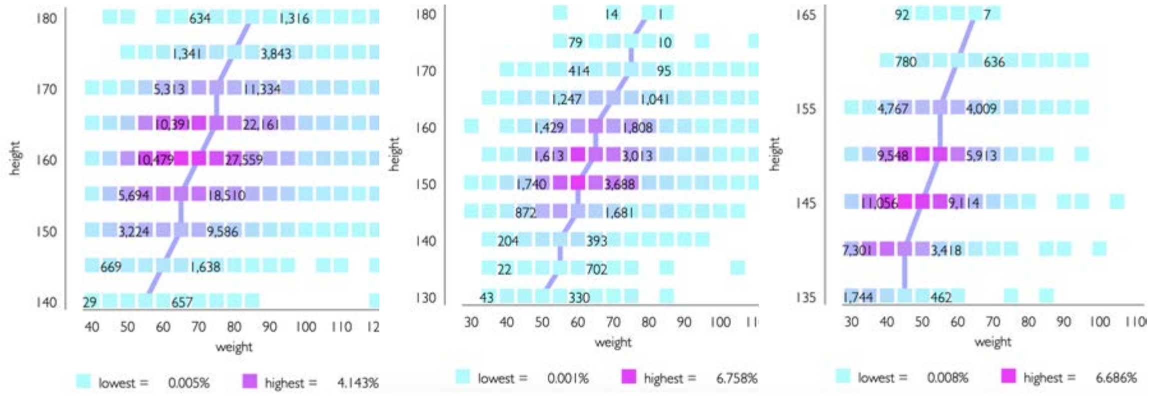
Figure 3: Number of lives saved by moving to optimum weight

Men



USA Mexico Indonesia

Women



USA Mexico Indonesia

Notes: Our data sources are waves, conducted between 2002 and 2016, of the Health and Retirement Study (HRS) for the U.S., the Mexican Health and Aging Study (MHAS) for Mexico, and the Indonesian Family Life Survey (IFLS) for Indonesia. Each dataset is rectangularized between waves, with missing information on individual weight and height interpolated using nearest neighbourhood imputation. Individuals are followed until death or attrition from the sample. Individuals are followed until death or attrition from the sample. Weight and height data from the four years prior to when survival or death is observed are excluded (to account, in part, for weight loss approaching the time of death). The top and bottom percentile of the BMI distribution are trimmed from the MHAS and IFLS samples because the top and bottom percentiles of height and weight are top-/bottom-coded. Each panel shows minimum mortality risk curves from Figure 1 together with two-dimensional histograms representing the distribution of each sample's height and weight. These histograms are constructed using 5cm x 5kg bins of height and weight and are displayed as square fields with a color gradient, ranging from light blue to dark purple, representing lowest to highest relative frequencies, respectively. The predicted numbers of averted deaths on the fourth year from when every individual were to move to her/his mortality-minimizing weight, are calculated using sampling weights for the most recent survey wave available for each country (2016 for the U.S., 2014 for Mexico and Indonesia). They report the difference between expected mortality associated with actual weights, given height, and mortality risk associated with mortality-minimizing weights, given height.

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Supplement

A Data

A.1 Data sources

The data sources in the analyses are the Health and Retirement Survey (HRS) for the United States, the Mexican Health and Aging Study (MHAS) for Mexico, and the Indonesian Family Life Survey (IFLS) for Indonesia. We use harmonized versions of the HRS and MHAS available through the Gateway to Global Aging platform (`https://g2aging.org/`). The HRS and MHAS data are longitudinal surveys representative of national populations aged 50 years and older in each survey year. Both also include respondents' spouses or partners (regardless of age). The IFLS is a longitudinal household survey conducted less frequently and including a larger age range (individuals aged 26 years and older. It is not nationally-representative, but instead is representative of 13 major Indonesian provinces, accounting for 83% of the total Indonesian population. Beginning in 2007-08, the IFLS was redesigned to collect information on health and retirement behavior comparable to the HRS family of surveys.

All three longitudinal surveys include individual-level information on height, weight, and mortality as well as a wide-range of socio-economic and demographic characteristics. Bodyweight and height are objectively measured in the IFLS, while in the HRS and MHAS they are self-reported. The objective measurement of height and weight in HRS started in 2006 for a subsample of the individuals. To maintain comparability across waves we use self-reported measures throughout the entire analysis period. In our analyses, we focus on anthropometric measures, demographic characteristics, and deaths (including dates of death). Table A1 summarizes the main features of the three data sources.

Table A1: Data sources

	USA **HRS**	**Mexico** **MHAS**	**Indonesia** **IFLS**
Waves	2000/01, 2002/03, 2004/05, 2006/07, 2008/09, 2010/11, 2012/13, 2014/15 , 2016/17	2000/01, 2002/03, 2012/13, 2014/15	2000, 2007/2008, 2014/15
Survey type	Household level, Longitudinal , Self-reported	Household level, Longitudinal , Self-reported	Household level, Longitudinal , Self-reported
Target population	Age 50+	Age 50+	All ages (26+)
Sample size and other characteristics	Around 44,000 individuals	Around 15,000 individuals	Around 33,000 individuals, with above 90% re-contact rate each year, the survey sample represented about 83% of the Indonesian population, and as the population aged, it turned comparable to HRS style data collections

Notes: The data come from Health and Retirement Study (HRS) in the U.S., the Mexican Health and Aging Study (MHAS) in Mexico, and the Indonesian Family Life Survey (IFLS) in Indonesia, waves between 2000 and 2016.

A.2 Data selection and sample construction

Our final samples are restricted to individuals ages 50-79 years. The HRS and MHAS do not sample individuals younger than 50, and there are few individuals in any of our data sources ages 80 years and above. We note that the age range of our samples differs from Fogel (1994), who focuses on individuals ages 50 to 64 years using data collected by Waaler (1984). Waaler (1984) combined information on height and weight obtained from the State Mass Miniature X-ray Examination carried out between 1963 and 1975 in Norway with the death register data for years 1963-1979 from the Norweigan Central Bureau of Statistics.

We pool all available waves of each survey conducted between 2000 and 2016 (separately by country and gender - yielding 6 subsamples). The timing of HRS, MHAS, and IFLS waves differ, as Table A1 shows. HRS waves are conducted every other year, so we use a total of 9 waves between 2000/01 and 2016/17. MHAS waves are conducted less regularly, with a substantial interval between the second and third wave in particular, yielding 4 waves total. Three IFLS waves were conducted between 2000 and 2016.

We exploit the longitudinal nature of each survey to track individual respondents over time. Given that different surveys were fielded at different times (and with different intervals), we apply a "rectangularization" procedure to each. Specifically, for years in which no data was collected, we interpolate missing information on weight and height at the individual level using nearest neighbor imputation until each individual either dies or exits from the survey. Our samples are necessarily unbalanced because new 50-year-olds enter the survey and dying/exiting individuals leave the survey over time.

Unlike Waaler (1984) and Fogel (1994), our longitudinal rectangularized data allow us to control for the time lag between measurement of height/weight and death. This is important because in addition to chronological age, time to death is also associated with the onset and subsequent rate of weight loss (Alley et al., 2010). Several studies suggest that pre-existing occult disease may be produce higher mortality at lower levels of body mass index (BMI) (Allison et al., 1999). We therefore exclude height and weight measurements within 4 years of the time that we analyze death/survival, producing a consistent temporal separation between anthropometric measurement and the time we observe death (or survival) in all of our samples.

Finally, to remove undue influence of outliers (which may in part also reflect measurement error), we trim the bottom and top percentile of the BMI distribution from each of our six sub-samples. In the MHAS and IFLS data, we also top-code the top and bottom percentile of the weight and height distributions.

Descriptive statistics for each sample are presented in table A2.

Table A2: Descriptive statistics

	HRS - USA		MHAS - Mexico		IFLS - Indonesia	
	Men	Women	Men	Women	Men	Women
Raw data						
	2000-2016		2000 - 2015		2000 - 2014	
Age (years)	62	63	61	61	60	61
Weight (kg)	90	75	74	66	56	51
Height (cm)	177	163	166	156	160	149
BMI	28	28	27	27	22	23
Disease	.62	.58	.42	.57	.05	.07
Death	0.013	0.010	0.008	0.006	0.013	0.001
N	76.254	96,719	25,133	30,004	9,509	11,490
Rectangularized data						
	2000-2016		2000 - 2015		2000 - 2016	
Age (years)	62	63	61	61	60	61
Weight (kg)	90	75	74	66	55	49
Height (cm)	177	163	166	156	160	148
BMI	28	28	27	27	22	23
Disease	.61	.57	.43	.61	.02	.02
Death	0.013	0.010	0.010	0.007	0.023	0.017
N	97,857	121,399	57,706	66,141	28,603	35,484

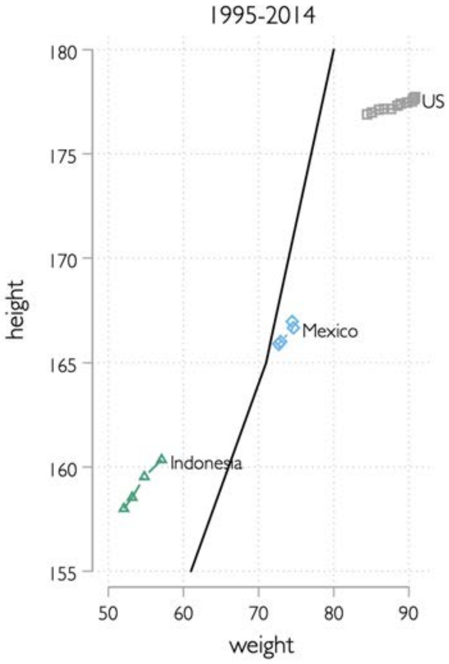
Notes: The data come from Health and Retirement Study (HRS) in the U.S., the Mexican Health and Aging Study (MHAS) in Mexico, and the Indonesian Family Life Survey (IFLS) in Indonesia. Each dataset is rectangularized by filling in the data between two subsequent waves, the missing information on weight and height at the individual level is interpolated with the nearest neighbourhood imputation. Individuals are followed until death or attrition from the sample. Weight and height data from the four years prior to when survival or death is observed are excluded (to account, in part, for weight loss approaching the time of death). The top and bottom percentile of the BMI distribution are trimmed from the MHAS and IFLS samples because the top and bottom percentiles of height and weight are top-/bottom-coded. The statistics in the first panel refer to raw data relative to the waves carried out, while the second panel refers to rectangularized data constructed by filling in the missing information for the periods where the data collection was not carried out.

B Descriptive statistics and additional results

B.1 Evolution of body weight over time

Figure B1 relates the minimum risk curve derived by Fogel (1994) based on Waaler (1984) sample of Norweigen males, to average heights and weights over time for males ages 50 - 79 years in the HRS, MHAS and IFLS. In the United States, average stature (or height) has generally remained constant over time, while average bodyweight has increased - already to the right of Fogel's minimum risk curve in 1995, and systematically moving further above it by 2014. In Mexico and Indonesia, average stature has steadily risen over time, and average bodyweight has as well - in Mexico, starting near the minimum risk curve and rising above it over time, and in Indonesia, moving towards it (but still remaining below it as of 2014).

Figure B1: Population average heights and weights trend and Waaler's minimum mortality risk curve for elderly males (ages: 50 - 79) - Source: HRS, MHAS and IFLS data



Notes: The data come from Health and Retirement Study (HRS) in the U.S., the Mexican Health and Aging Study (MHAS) in Mexico, and the Indonesian Family Life Survey (IFLS) in Indonesia, all available waves between 1995 and 2014 for men aged 50-79. The black line is the Fogel (1994) minimum mortality risk curve based on the Norwegian data.

C Methods

C.1 Estimation

Following Fogel (1994), we estimate iso-mortality curves as a function of weight and height. However, unlike Fogel (1994), we estimate these relationships using individual-level data, separately for men and women, controlling for age and treating each year as an independent cross-section. Specifically, for each country and gender sub-sample, we estimate probit models for mortality as a function of height and weight using the following general specification:

$$Death_{it} = \alpha + \beta_1 H_{it-4} + \beta_2 H_{it-4}^2 + \gamma_1 W_{it-4} + \gamma_2 W_{it-4}^2 + \delta W_{it-4} * H_{it-4} + \lambda Age_{it} + \epsilon_{it} \quad (1)$$

$Death_{it}$ is the death of individual i in period t, H_{it-4} and W_{it-4} are height in meters and weight in kilograms measured four years prior to period t (we include squared terms of each and an interaction between them as well), Age_{it} is age in years, and ϵ_{it} is an idiosyncratic error term clustered at the individual level. The estimates are computed using sampling weights. Table C1 presents probit marginal effects of coefficient estimates in the six models respectively.

We use coefficient estimates for each country and gender to predict individual mortality risk on a smooth grid of height/weight combination in intervals of whole centimeters/ kilograms holding age constant at 60. We use these predictions to plot the three-dimensional surfaces shown in Figure 1 in the body of the text, with colors corresponding to different level-sets of mortality risk. Additionally, we also use these predictions to generate minimum risk lines. These minimum risk lines are defined by

Table C1: Probit estimates

	HRS - USA		MHAS - Mexico		IFLS - Indonesia	
	Men	Women	Men	Women	Men	Women
weight	0.000609	0.000888	0.000689	0.000737	-0.00238	0.00226
	(0.00102)	(0.000656)	(0.00196)	(0.00149)	(0.00354)	(0.00253)
weight*weight	-0.00266	-0.00249	-0.00205	-0.00332	-0.000167	-0.00410
	(0.00288)	(0.00183)	(0.00303)	(0.00295)	(0.00721)	(0.00629)
height	1.47e-05	9.49e-06	1.04e-05	1.34e-05	3.41e-05	2.53e-05
	(2.36e-06)	(1.55e-06)	(6.09e-06)	(3.81e-06)	(1.16e-05)	(7.23e-06)
height*height	1.25e-05	1.09e-05	9.21e-06	1.36e-05	2.36e-06	1.99e-05
	(9.05e-06)	(6.07e-06)	(1.09e-05)	(1.14e-05)	(2.56e-05)	(2.30e-05)
weight*height	-1.89e-05	-1.41e-05	-1.40e-05	-1.62e-05	-9.91e-06	-3.38e-05
	(7.24e-06)	(4.71e-06)	(1.49e-05)	(1.17e-05)	(2.71e-05)	(1.98e-05)
age	0.00146	0.00118	0.00172	0.00107	0.00183	0.00153
	(5.71e-05)	(4.89e-05)	(0.000137)	(0.000103)	(0.000136)	(0.000111)
Pseudo R2	0.0554	0.0545	0.0925	0.0694	0.0355	0.0398
N	97,857	121,399	57,706	66,141	28,603	35,484

Notes: The data come from Health and Retirement Study (HRS) in the U.S., the Mexican Health and Aging Study (MHAS) in Mexico, and the Indonesian Family Life Survey (IFLS) in Indonesia, waves between 2002 and 2016. Each dataset is rectangularized by filling in the data between two subsequent waves, the missing information on individual weight and height is interpolated with nearest neighbourhood imputation. Individuals are followed until death or attrition from the sample. Weight and height data from the four years prior to when survival or death is observed are excluded (to account, in part, for weight loss approaching the time of death). The top and bottom percentile of the BMI distribution are trimmed from the MHAS and IFLS samples because the top and bottom percentiles of height and weight are top-/bottom-coded. The estimates are based on a probit response surface, with weights and heights products of maximum 2nd order for each dataset and gender separately. The controls include age in years. Standard errors are clustered at the individual level. The estimates are computed using sampling weights.

the locus of (height, weight) pairs that minimize mortality risk at each height; in practice, we use 5-centimeter intervals of height to construct the minimum risk curve shown in Figure 2.

We compute standard errors of the minimum probability estimates along each minimum risk line using block bootstrap procedure with 1,000 replications. Minimum probabilities with the standard errors are presented in Figure C1.

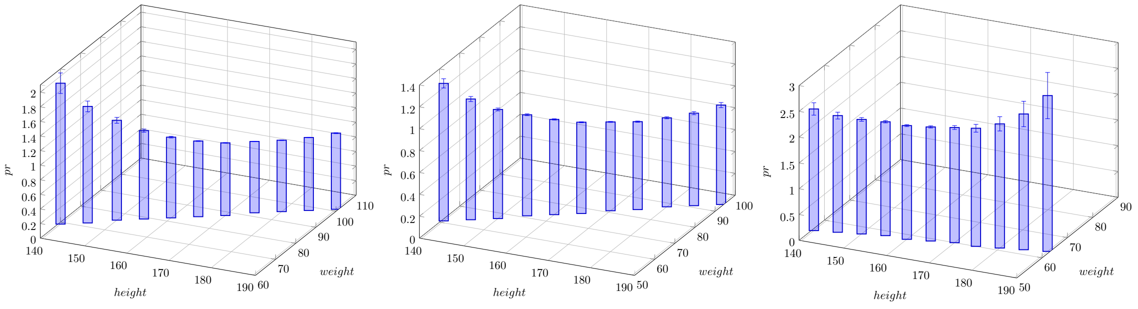
C.2 Implied mortality reduction calculations

Given each country by gender minimum mortality risk line, we compute the implied mortality reduction implied by our estimates (or curves) if all individuals were to move to her/his mortality-minimizing weight (holding height constant). Specifically, we use our probit estimation framework to generate predictions at observed weights and at risk-minimizing weights (given height), taking the difference between the two. We show these numerical results separately for individuals in each 5-centimeter height interval - and separately and among those below and above the minimum risk curve - in Figure 3.

The figure's color grid represents two-dimensional histograms of the joint distribution of height and weight in each sample, grouping sample density into bins of 5-centimeter height by 5-kilogram weight intervals. The color gradient ranges from light blue to magenta, reflecting lowest to highest relative frequencies, respectively, in the most recent survey year. We use sampling weights in these calculations to recover the implied number of individuals in each country-age-gender population (with population totals of 44 million men and 48 million women ages 50-79 in the US in 2016; 9.5 million men and 9.9 million women in Mexico ages 50-79 in 2014; and 19.6 million men and 20.1 million in Indonesia in 2014.

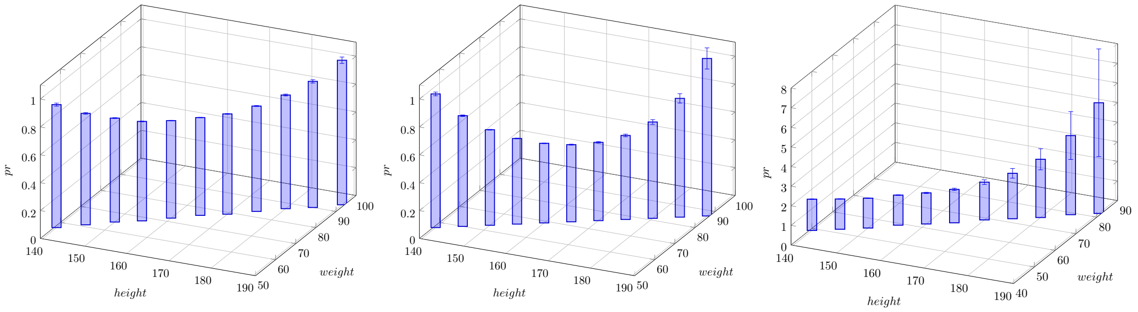
Figure C1: Minimum mortality probabilities with standard errors based on block bootstrap procedure.

Men



USA Mexico Indonesia

Women



USA Mexico Indonesia

Notes: The data come from Health and Retirement Study (HRS) in the U.S., the Mexican Health and Aging Study (MHAS) in Mexico, and the Indonesian Family Life Survey (IFLS) in Indonesia, waves between 2002 and 2016. Each dataset is rectangularized by filling in the data between two subsequent waves, the missing information on individual weight and height is interpolated with nearest neighbourhood imputation. Individuals are followed until death or attrition from the sample. Weight and height data from the four years prior to when survival or death is observed are excluded (to account, in part, for weight loss approaching the time of death). The top and bottom percentile of the BMI distribution are trimmed from the MHAS and IFLS samples because the top and bottom percentiles of height and weight are top-/bottom-coded. Each panel pictures minimum probabilities defined by the locus of (height, weight) pairs that minimize mortality risk and their standard errors computed using block bootstrap procedure with 1,000 replications, using estimates of probit response surfaces together with sampling weights, described in Supplement C.