Staff Paper P14-01 **January 2014**

Staff Paper Series

Agricultural R&D, Food Prices, Poverty and Malnutrition Redux

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2014-01-07

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Authorship is alphabetical. Paper prepared for presentation at the Festschrift conference on *New Directions in the Fight Against Hunger and Malnutrition*, held in honor of Per Pinstrup-Andersen, Cornell University, December 12–14, 2013. The work for this project was partly supported by the University of California; the University of Minnesota; the HarvestChoice initiative, funded by the Bill and Melinda Gates Foundation; and the Giannini Foundation of Agricultural Economics. The authors gratefully acknowledge excellent research assistance provided by Connie Chan-Kang.

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Introduction

Beginning in the early 1970s, Per Pinstrup-Andersen conducted pioneering work into the links between agricultural research and development (R&D) and its consequences for nutrition and health outcomes of the poor.[1] In this paper we revisit those links in the context of two twenty-first century conundrums. First, while many of the world's poor remain undernourished, paradoxically, growing numbers of people from a very broad range of income and social strata are overweight or obese. Second, rates of investment in agricultural research are slowing in many countries in spite of continuing high social rates of return to the investments, a trend toward higher food prices, and slowing rates of farm productivity growth in many countries.

It is widely acknowledged that public agricultural R&D has been a crucial policy for creating the era of agricultural abundance that now appears to be in jeopardy.[2] To what extent is this abundance that has saved and improved many millions of lives also responsible for the rise of obesity? What is the nature of the trade-offs between health and nutrition problems arising from increasing food abundance (or rising incomes) versus health and nutrition problems arising from food scarcity (or poverty)? What are the implications for policy? Should we use agricultural R&D as an instrument of public health policy or other dimensions of social policy?

One view is that agricultural R&D should be revitalized and refocused to enhance farm productivity growth and make food more abundant and cheaper, and thereby address problems of

[1] See, for example, Pinstrup-Andersen, de Londono and Hoover (1976), Pinstrup-Andersen (2007), Herforth, Jones and Pinstrup-Andersen (2012), and Pinstrup-Andersen (2013).

[2] For example, Easterbrock (1997) commented "Though barely known in the country of his birth, elsewhere in the world Norman Borlaug is widely considered to be among the leading Americans of our age ... Norman Borlaug has already saved more lives than any other person who ever lived ... Borlaug is responsible for the fact that throughout the postwar era, except in sub-Saharan Africa, global food production has expanded faster than the human population, averting the mass starvations that were widely predicted—for example, in the 1967 best seller *Famine-1975!* [the authors observed that] The form of agriculture that Borlaug preaches may have prevented a billion deaths."

poverty and food security that are foreseen through to 2050 (Ravallion 2013). Some suggest that we should ramp up research on fruits and vegetables at the expense of research on cereals and livestock products as a way of improving nutritional outcomes. Others may suggest that R&D should emphasize other dimensions of nutrition such as developing staple foods that are richer in specific micronutrients. In this paper we explore these competing ideas. We present up-to-date evidence on trends in agricultural research investments, productivity, and prices, connect them to patterns of human health outcomes around the world, and draw inferences for public R&D policy.

Economics and politics of agricultural R&D policy

Since around the middle of the 19th Century, the application of science to agriculture—increasingly by way of targeted investments in R&D—has released lots of labor and other (especially land) resources from the production of food and other agricultural outputs (Ruttan 1982). In 1800, before this R&D-induced process of agricultural transformation got underway, the planet's population was around 980 million people, most of whom lived and worked in agriculture (an estimated 75–80 percent of the working population of the time earned its livelihood in agriculture, see Bairoch 1988). Over two centuries later, in 2010, the world's population had increased sevenfold and now—although a significant number of people still live a hand-to-mouth existence, growing much or all of the food they consume—more than half the world's population lives in urban areas while less than 40 percent of the working population earn their livelihoods from agriculture.[3] Land used in agriculture worldwide increased by much less

[3] In fact, only 3.2 percent of the working population in high-income countries in 2010 was employed in agriculture, versus 64.5 percent of those in low-income countries (FAOSTAT 2013). See Pardey et al. (2014) and the references quoted therein for details of the source for these and the related data in this sub-section.

than global population, such that in 2010 agriculture had to feed 1.41 persons per hectare compared with just under one person in 1800.

The fact that the Malthusian nightmare has been largely averted is attributable in great part to remarkable gains in agricultural productivity achieved through technological change. Over the past 50 years, even though the world's population more than doubled and per capita incomes grew, compounding the growth in demand, the global food supply grew even faster. Real output from agriculture grew by 2.7 percent per year (equivalent to a 259 percent increase in real output from 1961 to 2010), and, in spite of the ever-tighter land constraint, agricultural output per person grew by 60.6 percent—from $209 per person in 1961 (2004-06 international prices) to $336 per person in 2010 (e.g., see Alston and Pardey 2014). Consequently, between 1961 and 2010, real prices of cereals fell by roughly 60 percent. These increases in land and labor productivity were accomplished by intensifying the use of "modern" inputs—in particular machinery, fertilizers and irrigation—combined with improved genetic material and methods of production increasingly derived from organized scientific research (e.g., see Pardey, Alston and Ruttan 2010).

A great many studies have found consistently high rates of return to the investments in public and private agricultural R&D (e.g., see Rao, Hurley and Pardey 2012). Double-digit benefit-cost ratios are typical. The benefits have accrued through enhanced farm incomes, lower costs of food production, reduced stress on the natural resource base, and the release of resources for other uses. The consequences can be seen in many measures of improved health and welfare, especially of the poor, though identifying the details of the complex pathways and attributing consequences among sources is challenging.

A reversal of fortune?

Recent trends are less salutary. By various measures growth rates of agricultural productivity have systematically slowed for most countries and for the world as a whole since 1990 if not sooner—for example, since 1960 cereal yields have grown essentially linearly, which implies a progressive slowdown in proportional growth (Alston and Pardey 2014). This productivity slowdown—along with other factors—is reflected in prices (e.g., see Alston, Beddow and Pardey 2009).[4] Following the price spike of the early 1970s, over the years 1975 to 2000, the index of real prices for cereals declined relatively rapidly but at a progressively slower rate. And since 2000 prices have increased (Figure 1).

[Figure 1: *Trends in prices and yields of cereals, 1961–2012*]

In the coming 50 years, significant growth in agricultural production will be necessary to meet the increasing food demands of a growing and richer (as well as aging and urbanizing) world population plus the ongoing but likely less-pronounced growth in the demand for bioenergy feedstocks (Pardey et al. 2014a). As in the past 50 years, much of this growth in production will have to come from increased productivity given a tightening of the scope for expanding the agricultural use of land and water. But simply sustaining current (let alone restoring the higher past) rates of productivity growth will require greater effort in view of the emerging challenges of climate change and the attendant implications for changing the abiotic (i.e., drought, temperature and so on) and biotic (i.e., pest and disease) stresses on agricultural plants and animals.

[4] Jorgenson and Griliches (1967) showed that under certain conditions (constant returns to scale and perfect competition), the ratio of the price index for inputs to the price index for output (the inverse of what is sometimes referred to as the farmers' terms of trade) is exactly equal to the primal measure of total factor productivity, TFP (or more precisely, in practice, multi-factor productivity, MFP). See also Alston, Babcock and Pardey (2010, pp. 456-457).

The contemporary trends in science policy run contrary to these arguments. In spite of the adverse implications of slowing productivity growth (e.g., Alston et al. 2010), and even though rates of return to agricultural research are demonstrably very high, we have seen a slowdown in R&D spending growth and a diversion of funds away from farm productivity enhancement, especially in the richest countries (Pardey, Alston and Chan-Kang 2013). China now spends more than the United States on public agricultural R&D, and the low- and middle-income countries are collectively outspending the group of high-income countries. These patterns seem to indicate that in the high-income countries, at least, governments are not much concerned about agricultural productivity, in spite of evidence of very large benefits from farm-productivity enhancing agricultural R&D.

Why is it so? Commonly, policymakers in the high-income countries in particular appear to discount the evidence on the returns to research, which demonstrate a persistent gross underinvestment, or to misunderstand the implications—or perhaps they simply care more about other things. In the 1980s some people said that investing in agricultural R&D was wasteful—at least in the high-income countries—because we were already overproducing farm commodities. This view reflected a misunderstanding of the fact that the important consequence of research has been to save resources on infra-marginal production, and make food cheaper to produce, such that research is valuable even if a commodity is in surplus, which is itself an unusual (government created) phenomenon. A more contemporary version of the same sentiment relates to obesity. Some say we already produce and consume too much of certain kinds of food—such as corn and other grains and livestock products—and we should cut back or cease undertaking R&D that enhances productivity of those foods in favor of R&D that promotes productivity in, and thus consumption of, foods such as fruits and vegetables that are perceived as being healthier and less fattening (e.g., Popkin 2010). In this paper we seek to provide more clarity on the interpretation of traditional measures, along with some less-traditional measures of the consequences of agricultural R&D for the poor.

What's agricultural productivity worth worldwide?

What might the world be like today if our forebears had opted not to make the research investments that enabled the Green Revolution and other changes in agriculture over the past 50 years? The counterfactual experiment of a world without the Green Revolution is hard to devise, even as a thought experiment—for example, what might the world be like if Norman Borlaug had become a professional wrestler (his early vocation) or a forester (his initial career choice) instead of a plant pathologist cum breeder?.[5] One version of this idea is to consider the consequences today if we were to revert to the patterns of agricultural productivity that existed in 1961, holding current input use constant. In Table 1 the first column is the index of total factor productivity (TFP) in country *j* in 2009 ($TFP_{j,2009}$) given a base of $TFP_{j,1961} = 100$ in 1961 as estimated by Keith Fuglie (Fuglie et al. 2012), which we take as read for this purpose. For the world as a whole this index is 225, equivalent to cumulative growth of 1.7 percent per year over the 48 year period, while for Brazil it is much higher at 276 (2.1 percent per year) and for Nigeria it is much lower at 144 (0.7 percent per year). In column 5 we report an approximate measure of benefits foregone if we reverted from 2009 to 1961 productivity levels—computed as $k_j{*}AgGDP_{j,2009}$—where $k_j = (TFP_{j,2009} - TFP_{j,1961})/TFP_{j,2009}$ and $AgGDP_{j,2009}$ (in column 2) is a measure of agricultural GDP for 2009 from the World Bank (2012) measured in 2005 international (PPP) dollars. For the world as a whole, this total benefit is estimated to be $3,658

[5] See www.cfans.umn.edu/AlumniFriends/awards/borlaug/borlaugthroughyears.

billion.[6] Arguably at least half of this total can be attributed to public and private investments in agricultural R&D, though precise attribution is impossible, and the attributable share will vary among countries and regions.[7]

[Table 1: *The 2009 value of agricultural TFP growth from 1961 to 2009*]

The benefits in column 5 are distributed reasonably congruently with total population in column 3—food is produced to a great extent within the countries and regions within which it is consumed—such that the benefits per capita in column 6, which average $299 for the world as a whole, are reasonably comparable among regions once we set aside the very low measure for Sub-Saharan Africa ($105). However, when we express these benefits per capita relative to GDP per capita from column 5, in column 6 we see that the benefits from agricultural productivity growth are much more important as a share of income for lower-income countries, even if the benefits per capita per se may be smaller than in the high-income countries. These benefits represent only 0.8 percent of GDP for the high-income countries but a more significant 3.2 percent of GDP in 2009 for the world as a whole, and well over 5 percent of GDP for the middle-income countries and the low-income countries. The ranking of countries now depends on both their growth rates of productivity and the country-specific relative importance of agriculture in the economy. Setting aside countries (mainly those in sub-Saharan Africa) where measured

[6] For comparison, in 2009 the world as a whole spent around $53 billion (2005 prices) on public and private agricultural and food R&D, roughly one-third of which was performed by private firms, and two-thirds was conducted in the public sector by national agricultural research agencies (Pardey et al. 2014b). In that year an additional $530 million (2005 prices) was invested in the international agricultural research centers of the Consultative Group on International Agricultural Research, CGIAR.

[7] The use of such approximations to measure the benefits from innovation attributable to research-induced productivity growth can be traced back at least as far as Griliches (1958). This application has three elements of awkwardness. First, in principle, we would prefer to apply the “k” factor to the gross value of production (GVP), whereas AgGDP is a value-added measure. The discrepancy between AgGDP and GVP is likely to vary systematically with per capita incomes, with AgGDP representing a smaller share of GVP in the higher-income countries. Second, public and private agricultural R&D are responsible for only a fraction of the total growth in TFP, and this difference also will vary systematically among countries depending on the stage of development. Third, the measures of TFP growth are likely to be more accurate for the higher-income countries, if only because they are more likely to have appropriately detailed data available in suitably long series.

agricultural TFP failed to grow over the past half century, Figure 2 clearly illustrates how the relative economic importance of productivity growth in agriculture increases as per capita incomes decline.[8] This pattern of relative importance of gross benefits from agricultural productivity growth helps to account for the observation that policymakers in the high-income countries appear to be relatively unconcerned with farm productivity nowadays.

[Figure 2: *The comparative economic importance of agricultural productivity growth, 2009*]

Of course, the benefits from agricultural productivity growth are not distributed uniformly among households within a country—especially when we take into account that, through international commodity trade, productivity growth in one country can affect prices in another. Agricultural technology induces changes in the distribution of income among and within households, through a multitude of direct and indirect effects and the optimizing responses of the households. Even if agricultural technology has no direct effect on household incomes, it affects food security or poverty through its effects on the price of food. Benefits accrue to (farm) households both (a) through reductions in the costs of production (for those that adopt the technology), and (b) through reductions in the *net* costs of food purchases (the difference between their expenditure on food consumption and the value of their production) resulting from the fall in price. For food deficit households, the fall in price means a benefit; for food surplus households, it means a loss. In addition to these two direct sources of benefits, households may gain (or lose) indirectly from induced adjustments in factor markets in which

[8] Productivity estimates from Fuglie et al. (2012) indicate that 24 (out of 155) countries for which we have corresponding agricultural GDP estimates failed to sustain positive TFP growth in agriculture since 1961, and that 13 (55 percent) of those countries were in sub-Saharan Africa. In turn these 13 countries had 2009 research intensity ratios (i.e., the share of agricultural R&D spending relative to agGDP) of just 0.5 percent (compared with a global average of 1.0 percent), and one third of these countries were spending less in inflation-adjusted terms on public agricultural R&D in 2009 than they were in 1961.

they participate as well as broader, general equilibrium impacts (e.g., Alston, Martin and Pardey 2014).

Figure 3 compares two stylized distributions of household income across households, conditional on the state of technology and a given draw of exogenous factors that gives rise to particular price outcomes (see Alston, Martin and Pardey 2014). The income distribution across households, given technology τ_0, is denoted Y_0^e. Associated with this distribution, and defined by the corresponding prices is a "poverty line," reflecting the cost of a minimal quantity of food (or food calories) and other necessities, drawn at L_0^e. Under the alternative technology scenario, τ_1, but for the same draw of exogenous factors, food prices are lower and the poverty line is shifted to L_1^e, reducing the fraction of the population living in poverty for a given income distribution. This can be a big effect if we have a big change in the price of food, even with no direct changes in household incomes of the type that result from the effects of adoption of new technologies on reducing costs of production and the effects on household revenues induced by price changes. When the distribution of income shifts to the right from, say, Y_0^e to Y_1^e as a result of shifting from technology regime τ_0 to τ_1, the fraction of the population living in poverty is further reduced.[9]

[Figure 3: *Agricultural technology and household income distributions*]

A large and growing fraction of the world's poor are nonfarm rural or urban dwellers whose only direct economic benefits from agricultural productivity growth will be through the impacts on food prices—whether as a result of changes in technology in their own country or elsewhere in the world. If we were to revert to 1961 farm productivity patterns today, other

[9] Even though some farmers will be made worse off (if, for instance, they are surplus producers and cannot adopt the new technology), the distribution generally shifts to the right, as drawn, reflecting the general improvement in incomes for households although some have shifted to the left within the distribution.

things held constant, farm commodity prices would be much higher than they were in 1961 given the much greater population and higher per capita incomes. For the very poor who are net buyers of farm products, the real income consequences of such an increase in prices would be very serious—devastating for many—as illustrated by the events following the commodity price spike in 2007.

To illustrate the regressive, negative real income consequences of an increase in food prices, Figure 4, Panel a arrays countries from lowest (Zimbabwe) to highest (Qatar) in terms of per capita income and reveals how the marginal dollar of income is spent across seven broad consumption categories. The low-income countries (to the left of the figure) spend an average of 47 percent of their marginal income on food, compared with just 13 percent by the rich-countries on average. The shares of extra income spent on transportation and communication, as well as recreation and furniture, housing and clothing, all increase as per capita incomes increase. Notably, while the share of marginal income devoted to food, beverages and tobacco expenditures declines as per capita incomes increase, conversely the marginal budget share of health and medically related expenditures increases (Figure 4, Panel b).[10]

Thus, the increase in real income from a fall in food commodity prices will have a much greater effect on the food budget and thus nutritional opportunity for the average person in a low-income country, who spends 47 percent of marginal income on food—having average per capita income of just $1,031 (2005 PPP prices) in 2010—compared with the average resident of a rich-country, who spends only 13 percent of marginal income on food—having average per capita income of $33,112 in 2010.[11]

[10] The specific linear relationship shown in Figure 4, Panel b follows directly from the functional form of the model applied by Muhammed et al. (2011), but the general pattern of a negative relationship is to be expected given the expected sizes of the elasticities of demand for food and health care with respect to total expenditure (or income).

[11] Raw commodities represent a larger share of the total budget for the poor partly because as incomes rise

[Figure 4: *Country average marginal expenditure shares by per capita income, 2005*]

While we have abundant money-metric measures of the returns to agricultural research (such as benefit-cost ratios and internal rates of return), we have much less concrete evidence on the consequences for food security of the poor or more generally how the benefits from agricultural R&D are distributed among consumers, producers, agribusiness interests and the like. More acutely lacking is a useful set of indicators of the extent to which agricultural R&D has affected nutrition and health outcomes, including infant mortality rates, life expectancy, and morbidity. Indicators of this nature may be effective in persuading policymakers to continue to invest in agricultural R&D where the standard money metric measures are not. Certainly, a claim that Norman Borlaug has saved a billion lives (as by Penn and Teller—see Jillette and Teller 2009) captures the imagination more effectively than any claims about the dollar value of his accomplishments. With this thought in mind, we next present some nutrition-health related indicators, followed by some exploratory assessments of the implications of realigning investments in agricultural R&D to target certain nutrition outcomes.

(Mal)nutrition, health and agriculture

Quantifying the relationship between R&D spending and agricultural productivity growth is tough enough. Clarifying the complex, cloudy, and sometimes confounding associations between agricultural production and productivity growth (and the commodity composition of that growth) and the human nutrition and health outcomes associated with food consumption is especially daunting, doubly so when drawing on aggregate data. Here we summarize some of

consumers demand more services associated with food as well as other nonfood items that also have larger elasticities of demand with respect to total expenditure. Thus, for the poor people in poor countries who typically eat less processed and more home-prepared foods, commodity costs represent a larger share of their food budget, which itself represents a comparatively large share of the total budget.

the scholarship linking various anthropometric attributes to nutrition and other factors (from a broad historical perspective), complemented by some of the available empirical evidence on global poverty, malnutrition and mortality. This provides a basis for beginning to build the conceptual and empirical bridges linking R&D, agricultural productivity and anthropometric indicators to help calibrate thinking about the appropriate policies and priorities regarding agricultural R&D over the decades ahead.

Anthropometric angles on agriculture, food and health

Cutler, Deaton and Lleras-Muney (2006) critically assessed the reasonably extensive literature regarding the determinants of mortality, including its historical decline and the prevalence of premature death in today's poor countries. They singled out improvements in nutrition and public health along with urbanization, the avoidance of disease, and modern medical, especially therapeutic, treatments as putative factors accounting for the decline in mortality over time. Drawing on the work of Fogel (1997), Costa and Steckel (1997), and others, they concluded that the century of mortality decline in Europe (and presumably in other places with similar incomes) that began in the middle of the 18th Century owed much to improvements in nutrition and economic growth.[12] This transitioned to a second phase beginning in the late 19th Century in which "… improvements in public health [including sanitation, filtered and chlorinated water, and mass vaccinations] mattered more" (Cutler, Deaton and Lleras-Muney 2006, p. 106), followed by a third phase, from the 1930s onwards, in which medical treatments dealing with diseases and injuries became a primary driver of reduced mortality.

[12] However, some dispute this view (e.g., see, Feinstein 1998 and Easterlin 2004). Moreover, citing work by Livi-Bacci (1991) and Harris (2004), Cutler, Deaton and Lleras-Muney (2006, p. 101) noted that "Another concern with the nutritional story is that, from the sixteenth to the eighteenth centuries, English aristocrats had no life expectancy advantage over the rest of the population, despite presumably better nutrition. Nor was mortality lower in well-fed populations of the same period, such as in the United States."

Diseases and mortality

A host of anthropometric indicators are used to reveal different dimensions of human health: including height and weight (for age), body mass and other under- and over-nourished (e.g., obesity) related metrics such as the prevalence of nutrition-related diseases, hypertension, diabetes, blindness, cognitive ability, and so on. One of the most prevalent and arguably amongst the most compelling indicators is average life-expectancy-at-birth (Figure 5).[13] Using Johansson and Lindgren's (2013) compilation, the worldwide average life-expectancy-at-birth in 1800 was just 31 years; ranging from 23 to 25 years for Yemen, Sierra Leone and Senegal to 39 to 40 years for the United States, Netherlands, and Belgium. By 2010 the global average had jumped to 70 years overall (ranging from 45 years for Sierra Leone and Haiti to 82 years for Switzerland, Hong Kong, and Japan). The regional pattern of increase is quite uneven. The rich countries reached an average life-expectancy-at-birth of 40 years by 1885, but it took another 38 years until people in Eastern Europe and the Former Soviet Union (EE&FSU) lived that long on average. The sub-Saharan African region did not reach the 40-year threshold until 1960, by which time the average life-expectancy-at-birth of people living in the rich countries had increased to 69 years.

[Figure 5: *Average life expectancy at birth by world region, 1870–2012*]

The Johansson and Lindgren (2013) data indicate that all the 201 countries around the world for which they developed estimates had an average life-expectancy-at-birth in 2010 that was greater than the rich-country average of 40 years in 1885, the end of the first phase of mortality reduction in Cutler, Deaton and Lleras-Muney (2006). Thus most of the world's

[13] In the data we use here, life expectancy at birth in a given year is defined as "… the average number of years a newborn child would live if current mortality patterns were to stay the same" (Johansson and Lindgren 2011, p.1)—measured, as the average age of people who died in that year, or, in other words, the average length of life to that point in time. A measure that reflects morbidity as well as mortality outcomes, such as disability-adjusted life years (DALYs), is an alternative anthropometric indicator (see, for example, Murray et al. 2013).

population is now living longer, and in many instances much longer, than did their rich-country counterparts in the late 19th Century. Still, even as late as the middle of the 20th Century the regional (and country) spread in life expectancy was much greater than it was at the beginning of the 19th Century. However, over the past half century, average life expectancies in most regions of the world have been closing in on the still growing average life expectancy in the rich countries.[14]

The outlier is sub-Saharan Africa, where life-expectancy-at-birth averaged 55 years in 2010, equivalent to the average life expectancy reached by today's rich countries back in 1930. In this region only 58 percent of the population has access to potable water and just 31 percent has access to sanitation (and one third of the population defecate out-of-doors, over 40 percent in rural areas); average per capita income is just $1,074 (2005 PPP prices) per person (compared with a rich-country average of $33,112 per person); 69.2 percent of the population live on less than $2 per day, with food consumption of just 1,577 calories per person (versus 2,194 calories per person on average in rich countries); and there are just 0.16 physicians per 1,000 people (versus 2.9 per 1,000 in the rich-countries).[15] All the factors that Cutler, Deaton and Lleras-Muney (2006) associate with higher mortality rates are evident here.

An association between life expectancy and per capita income over the long term is revealed in Figure 6. The comparatively tight clustering of life expectancies in 1800 is once again evident in Figure 6, Panel a; an era when cross-country differences in per capita income were also muted, most of that income was being earned in agriculture, and before the advent of

[14] The estimated national average life-expectancy-at-birth in 1800 ranged from a maximum 40 years for Belgium down to 23 years for Yemen. In 2010 the spread was from 45 years for Sierra Leone to 83 years for Japan.

[15] The data on potable water and sanitation are from Banerjee and Morella (2011), the data on per capita income and physicians per capita are from World Bank (2013), the data on poverty are from Chen and Ravallion (2012), and the data on consumption are from FAO (2013). The water and sanitation data are for 2006, the poverty data for 2008, the physicians per capita data for 2009, and the rest for 2010.

modern sanitation, public health and science-based medical services anywhere in the world.[16] Comparing Panel a with Panel b in Figure 6, over two centuries later, in 2010, two key developments are evident. At any particular level of income, people live substantially longer than they did in the past. Second, the spread in life expectancies among countries is now more pronounced and appears to be positively, but not exclusively, related to per capita income. While per capita income affects food consumption along with access to and use of education, information, sanitation, medical and other health-promoting goods and services, many of these factors affect life expectancy in different ways in different phases of a person's life (fetal, immediate post-natal, and later in life). These various and variable inter-temporal effects linking per capita income over a lifetime both directly and indirectly to the timing of mortality thus confound the relationship between the data on average life-expectancy-at-birth in a specific year and contemporaneous measures of average per capita income. Preston (1975, 1980 and 1996), for example, estimates that increases in income alone account for only 20 percent of the increase in life expectancy.

[Figure 6: *Per capita income and average life expectancy at birth, 1800 and 2010*]

Mortality is an affliction that affects us all, sooner or later. However, the notional causes of mortality vary across countries, and over time within countries. WHO (2011) data indicate that in 2008, a total of 50 million people died, and most (70 percent of the global total) of those deaths occurred in the middle-income countries. The generally older and smaller populations of the richer countries had a total of 7.2 million deaths (14 percent of their total), while 7.8 million people (15.5 percent) died in the increasingly populous but younger populations of the low-income countries. Figure 7 summarizes the numbers, shares and rates of death according to

[16] The flush toilet was first popularized (initially in Britain and Europe) around the middle of the 19th Century; the initial clinical application of penicillin in the early 1940s ushered in the modern era of antibiotics; and anti-retroviral treatments for HIV-infected people followed from scientific evidence on the viral dynamics of this disease in 1996.

various categories of diseases and injuries attributed as the cause of death. Death rates (i.e., the number of deaths per 100,000 people) generally increased as per capita incomes decreased, with 1,014 deaths per 100,000 people in low-income countries, 51 percent higher than the 672 rate of death in high-income countries. Average death rates of upper-middle-income countries were similar to those of high-income countries, whereas average death rates in the lower-middle-income countries fell between the low and upper-middle income averages.

[Figure 7: *Global deaths by category of disease and injury, 2008*]

Higher-income countries tend to have older populations, while the populations in lower-income countries are generally younger. Figure 8 stratifies countries into several per capita income and age cohorts. Cancers led to many more deaths in high- and upper-middle-income countries compared with the rest of the world, and most of those deaths involved the elderly. Most of the deaths attributed to cardiovascular diseases and diabetes also occurred in people over 60 years of age, but most of these deaths occurred in the middle-income countries. Around 81 percent of the worldwide deaths attributable to HIV, tuberculosis, and malaria occurred in the lower-middle- and low-income countries and largely afflicted those less than 14 years of age. The lower-middle- and low-income countries also accounted for 90 percent of the worldwide deaths attributed to maternal, perinatal, nutritional and diarrheal diseases, and within the low-income countries 19 percent of all deaths were associated with this group of diseases. Moreover, most of the deaths occurred among the young: 7.9 million children 14 years of age or less died from these diseases in lower-middle- and low-income countries, 0.96 million in the upper-middle- and high-income countries. A recent analysis by Black et al. (2013) estimated that in 2011, 3.1 million children under the age of five died from undernutrition, accounting for 45 percent of total child deaths worldwide in that year.

[Figure 8: *Global deaths by age, income and category of disease and injury, 2008*]

Figure 9, Panels a-c, show the numbers of deaths associated with nutritionally-related diseases in 2008. Most of those deaths occurred in middle-income countries (Panel a), but the more detailed causes of these deaths vary markedly across countries grouped by per capita income (Panel b). High- and upper-middle-income countries look similar on this score, where diseases associated most commonly with over nutrition (i.e., cerebrovascular, diabetes and hypertensive heart disease) accounted for over 95 percent of the nutritionally related deaths in both groups of countries. In stark contrast, deaths from disease associated with contaminated food or undernutrition (i.e., diarrheal disease, prematurity and low birth weight, and "nutritional" diseases in WHO parlance) accounted for 31 percent and 48 percent of the deaths in lower-middle- and low-income countries respectively. Over 63 percent of those "nutritional" related deaths were associated with protein-energy malnutrition (Panel d).

[Figure 9: *Deaths caused by nutrition-related diseases, 2008*]

Obesity

The worldwide prevalence of obesity has increased rapidly and the related health concerns are priority issues for governments and the medical community worldwide (e.g., see WHO, 1997; International Obesity Task Force, 2005). WHO (2013) data indicate that over one-fifth of the population in high-income countries was obese (BMI values of 30kg/m2 or higher) in 2008.[17] The respective low- and middle-income shares were 3.2 and 10.1 percent respectively, but these averages mask substantial regional differences. For instance, only 4.2 percent of the people living in the Asia and Pacific region were deemed obese (and 7.6 percent of those living

[17] BMI, or body mass indexes, are expressed as mass (in this instance kilograms) per height (meters) squared.

in sub-Saharan Africa) versus 23.6 percent of the population in the Latin America and Caribbean region.

In addition to the substantial personal costs they bear, obese and overweight people generate large additional direct and indirect health-care expenses (for instance, Parks, Alston and Okrent 2012 estimated that $181.1 billion or 16.6 percent of U.S. public medical expenditures in 2009 could be attributed to obesity). However, the appropriate policy, if any, for reducing obesity is not clear. Some potential policies work through the use of food prices as incentives. Non-economists and economists alike appear to take the view that food prices should matter for consumption choices and the resulting obesity outcomes. Such thinking underpins various proposals for introducing tax or subsidy policies to discourage less-healthy and encourage more-healthy consumption choices, and some such proposals work through prices of farm commodities used to make food. Economic studies have consistently found that farm subsidies have had negligible impacts on U.S. obesity patterns; however some have suggested that public agricultural research and development (R&D) may have contributed to obesity by making farm commodities cheaper and more abundant.[18]

Agricultural R&D as obesity policy

In real terms, the prices of major agricultural commodities have fallen by 50 percent or more since 1950, and agricultural R&D has been credited as a primary engine for those changes. In turn, these farm productivity gains have been reflected in lower prices of retail food products (e.g., Lakdawalla, Philipson and Bhattacharya 2005; Miller and Coble 2007, 2008). Lower food prices alone would be sufficient to encourage some increases in food consumption, but relative

[18] For instance, see Cutler, Glaeser, and Shapiro (2003); Alston, Sumner and Vosti (2006); Miller and Coble (2007); Alston, Sumner and Vosti (2008); Okrent and Alston (2012); and Rickard, Okrent and Alston (2012).

prices also moved in favor of the production and consumption of "unhealthy" foods that use field crops and livestock as ingredients, potentially making matters worse.[19]

A reasonable question is whether society would have been served better by a different pattern of private and public investments in agricultural R&D and technologies.[20] A corollary question, looking forward, is whether the agricultural research portfolio should be tilted more in favor of healthy foods, and away from less-healthy foods.[21] This is a complex question. Pertinent issues are (a) the extent to which it is possible to achieve public purposes related to obesity by changing the agricultural R&D portfolio, (b) the opportunity cost of conventional research benefits that must be foregone, through changing the mixture of research investments, in exchange for a given reduction in the prevalence of obesity, and (c) the extent to which these gains might be achieved at lower cost through the use of other policy instruments, more directly targeted at the problem of obesity (see Appendix A). Economic assessments consistently show remarkably high rates of return to public investments in agricultural research (e.g., Alston et al. 2011, report benefit-cost ratios in the range of 20:1 or 30:1 for the United States). These high benefit-cost ratios indicate that the total R&D portfolio is too small. An implication is that

[19] Some authors have argued that this is because productivity gains for fruit and vegetable farm commodities have been somewhat slower than those for field crops and livestock (e.g., see Drewnowski and Darmon 2005, Drewnowski and Specter 2004, Popkin 2010), but the detailed empirical analysis by Alston and Pardey (2008) does not support that view.

[20] For example, Popkin (2010) attributes the rise in U.S. obesity to a pervasive role of government in promoting the production and consumption of animal products, and a few grains and oilseeds, at the expense of other more healthy foods, both through direct subsidies and through public agricultural R&D. Many other writers on food and nutrition policy have echoed these sentiments. Like Popkin, these writers never clearly state the full details of the relevant counterfactual, however.

[21] Some such policies have been initiated. In the 2008 Farm Bill the U.S. government introduced the Specialty Crops Research Initiative, mandating funding of $50 million per year for FY 2009–12 and authorizing additional annual appropriations of $100 million for a new program of competitive research grants. More recently, a report from the Institute of Medicine (Glickman et al. 2012) recommended that the American Congress and the Administration "should ensure that there is adequate public funding for agricultural research and extension so that the research agenda can include a greater focus on supporting the production of foods Americans need to consume in greater quantities according to the Dietary Guidelines for Americans" (p. 435). Such recommendations have also been echoed within the medical community (e.g., Grandi and Franck 2012) as well as by policymakers (e.g., Whitehouse Taskforce on Childhood Obesity Report to the President 2010).

distorting that already-too-small portfolio with a view to achieving obesity objectives might impose very large social opportunity costs.

Recent empirical work supports that view in the case of the United States. Alston, Okrent and Parks (2013) investigated the effects of U.S. public investment in agricultural R&D on food prices, per capita calorie consumption, adult body weight, obesity, public health-care expenditures related to obesity, and social welfare. They used an econometric model to estimate the average effect of an incremental investment in agricultural R&D on the farm prices of ten categories of farm commodities. Next, they used the econometric results in a simulation model to estimate the implied changes in prices and quantities consumed of nine categories of food for given changes in research expenditures. Finally, they estimated the corresponding changes in social welfare, including both the traditional measures of changes in economic surplus in markets for food and farm commodities, and changes in public health-care expenditures associated with the predicted changes in food consumption and hence obesity.

Their results indicate that a 10 percent decrease in the stream of annual U.S. public investment in agricultural (and food) R&D in the latter half of the 20^{th} Century would have caused a very modest decrease in average daily calorie consumption of American adults, resulting in small decreases in body weight (1.75 lb per adult) and modest reductions in the external social costs of obesity ($3.8 billion in 2004). On the other hand, such a decrease in spending would have meant foregoing very substantial net national benefits given the very large benefit-cost ratios for agricultural R&D ($28.7 billion in benefits forgone in 2004). Thus the net social (opportunity) cost was estimated to be $63 for a reduction of one pound of average U.S. adult body weight. Similar results were found for other simulated changes in research spending. These measures suggest that changing agricultural R&D spending is an ineffective and very inefficient way to reduce obesity—perhaps more so when we consider the R&D lags which mean that any change in policy today might not begin to substantially affect prices, consumption, and obesity for 20 or 30 years.

Other policies are likely to be more effective and efficient as obesity policies. These could include policies to reduce the distortions from insurance pools and free public health care, educational programs, or other policies to encourage and facilitate healthier individual choices about food and exercise, including taxes and subsidies.[22] Much has been written about the use of taxes on farm commodities (e.g., corn), particular nutrients (e.g., sugar, fat), or particular foods (e.g., sugar-sweetened beverages) to combat obesity, and some jurisdictions have enacted policies in this genre. Okrent and Alston (2012) evaluated such policies using the same model as used by Alston, Okrent, and Parks (2013); hence, the findings are directly comparable. Okrent and Alston (2012) found that taxes on food based on its fat content, sugar content, or total caloric content would yield net social benefits. With these policies—unlike changing R&D spending to reduce obesity—the benefits from reduced excess health-care spending costs would outweigh the reduction in private benefits from consumption and production of food. Specifically, they found that (unlike the research policies which would entail a social cost to reduce obesity) the tax policies they evaluated would yield a net social benefit per pound reduction in U.S. average adult body weight (fat tax, $1.31 per pound of body weight; taxing all food, $1.54 per pound of body weight; sugar tax $1.73, per pound of body weight; caloric tax, $1.77 per pound of body weight). The greatest net benefit is for a tax on total calories, which is to be expected since that tax is more directly targeted on the source of the problem, an energy surplus. As the authors note, these results might understate the effectiveness of the tax instrument since they did not allow for

[22] Many of these policy options, like R&D, are not directly targeted on the economic distortion associated with obesity (mainly in excess costs of health care provision), and may be ineffective or inefficient for that reason. The issue becomes one of comparative effectiveness and efficiency of suboptimal policies in an n^{th}-best world.

changes in food manufacturing to adapt to the taxes, and any such taxes would be regressive on the poor.

Alston, Okrent, and Parks (2013) also simulated the effects of reverting in 2004 to the agricultural productivity pattern implied by the agricultural knowledge stock of 1980. The implication was for a decrease in average U.S. adult body weight in 2004 by 11 pounds, albeit at a very large social cost. While substantial, this represents only a fraction of the problem. In a broader economic context, Cutler, Glaezer and Shapiro (2003) attributed the rise in obesity primarily to changes in technology—but not so much to changes in farming technology that contributed to the abundance of farm commodities used to make food, as to the development and adoption of labor-saving technology used to prepare food and the concomitant rise of mass-prepared food.[23] Other technological innovations—e.g., in telecommunications and public and private transportation—may also have contributed by encouraging reduced physical activity.

Would anyone seriously propose reverting to the 1970s technologies used at home and by industry in producing and preparing and processing food, and in every other aspect of our daily lives, with a view to saving the excess social costs attributed to the increase in prevalence of overweight and obesity among Americans? Perhaps some true zealots may state such a position, even if they choose not to reject all modern technologies in their personal lives. But such a policy would be extraordinarily expensive for the economy as a whole and would be regressive on the poor.

What is the appropriate policy? In light of the arguments and evidence presented here, it would seem to be appropriate to have an R&D policy that emphasized reducing distortions in

[23] As shown by Alston, Sumner and Vosti (2008) international differences in prices of food, as captured by the Big Mac index, which reflects all of these factors, can account for some of the international differences in obesity prevalence.

research investments and worked towards maximizing net social benefits from research, and to use other instruments to tackle obesity—perhaps including some appropriately targeted food taxes as part of the policy set. Allowing for the presence of other economic distortions in the economy, as they influence the net social returns to different types of research investments, should not have large implications for the optimal research portfolio (see Alston, Edwards and Freebairn 1988, and Martin and Alston 1994). Although we do not have detailed comparable empirical evidence of the same type related to the trade-offs involved in using agricultural research to achieve other types of social objectives, we suspect the findings will be similar in general—the rationale is conceptual, not empirical.

Conclusion

It is appropriate to be concerned with recent trends in agricultural R&D policy for several reasons. First, by all indications available to us, the world is spending too little on agricultural R&D in total, and too little on certain types of agricultural R&D where institutions do not encourage private investment and governments have not sufficiently corrected the problem. As documented by Pardey, Alston, and Chan-Kang (2013), the world table is shifting with a rising role of the middle-income countries, a shrinking role of the high-income countries, and a continuing neglect in the poorest countries that may be the relevant focus of much of what we have discussed in this paper. Second, the scarce resources that are being made available for public agricultural research are increasingly being asked to serve a multitude of masters for which they may be little suited. In many places "agricultural" research resources are being diverted away from productivity enhancing research in farming and food production to pursue environmental, nutritional, health, or income distributional targets. In many instances, agricultural research will be an ineffective instrument for pursuing the target in question and, even if effective, it will usually not be the least-cost means for the job.

In this paper we have sought to elucidate to aspects of this situation. First, we have compiled a variety of measures that are suggestive of the view that agricultural R&D, directed at increasing the general abundance of food, generates a very large net social benefit *while at the same time* yielding great benefits for the health and well-being of the poor. Given the great and persistent underinvestment in productivity-enhancing agricultural R&D, as in the Green Revolution, we can continue to do much good for the poor while doing well for the economy as a whole simply by investing in those agricultural research areas where the total payoff will be highest. Second, as illustrated by the example of using agricultural R&D policy as obesity policy in the United States, the available empirical evidence indicates that it can be very counterproductive to seek to use public agricultural research as an instrument of social policy rather than using it as an instrument for correcting market failures in agricultural science.

Of course, the world is a much more complex place than our simple analytics can convey. In many places even second-best solutions will be far beyond the reach of practical policy. In the political reality of agricultural science funding, it will continue to be better to accept funding conditional on it being used for a particular—lower payoff—purpose if the alternative is to have an even worse problem of underinvestment in the total portfolio. Even so, having to compromise some of the time does not mean we should passively make the same kinds of choices when not constrained to do so given that the research portfolio that maximizes total net benefits from the investment stands a good chance of being the one that also yields the greatest benefits for the poor, their health, and their life expectancies.

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Appendix A: Agricultural R&D as an instrument of social policy

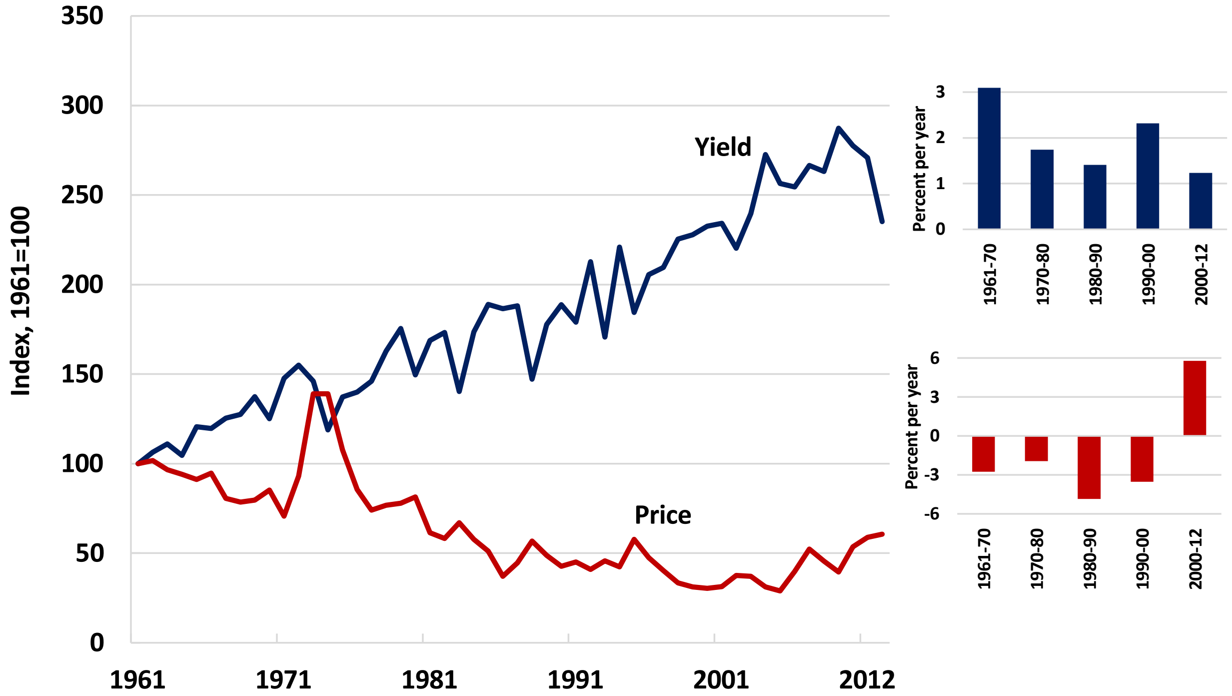
Governments use a range of policy instruments to pursue a range of social objectives related to human health and wellbeing, poverty, food security, the environment, and so on. Since agricultural R&D can have consequences for many of the human outcomes that are represented in this broad policy agenda, it seems natural for policymakers to want to consider these consequences in setting priorities for public agricultural R&D. Indeed, some propose to target agricultural R&D to achieve particular social objectives—such as healthier diets, better environmental outcomes, or reduced poverty—perhaps on the (mistaken) grounds that agricultural productivity is not a concern or that food is already abundant.

Such thinking suffers from several economic flaws. First, the fundamental economic rationale for public agricultural R&D is to correct market failures, mainly in the form of underinvestment arising from inadequate private property rights to inventions. Any diversion of public research spending away from the allocation that maximizes net social benefits necessarily compromises the primary purpose and the social benefit from the investment necessarily falls. Moreover, since we are grossly underinvesting in agricultural R&D, in spite of extensive government intervention, the opportunity cost of diverting agricultural funds to other purposes will be very high. Second, public agricultural R&D is not the only policy instrument available to the government. Other policies that are more closely targeted on particular social objectives are likely to be both more effective and more economically efficient than targeted agricultural R&D. Moreover, the economic relationships between research investments and social and economic outcomes are complicated and not transparently obvious. Indeed, it is conceivable that R&D targeted on a particular social objective may be less effective and less efficient and may contribute less to that purpose than non-targeted R&D would.

These ideas are illustrated in Figure A-1, which represents trade-offs between "efficiency" (E) measured by total benefits and "equity" (V) measured by benefits to a particular group as a share of the total. In this figure, BTC_R is the benefit-transformation curve for research that represents the combinations of efficiency and equity that could be attained by allocating different amounts of the total research budget to targeted research. Point **a** represents the attainable equity-efficiency combination that maximizes equity and point **b** represents the attainable combination that maximizes efficiency. Policymakers perceiving a trade-off between these two objectives as represented by the policy indifference curve, IC_0, might choose the combination at point **b** (E*, V*). However, if some other policy instrument could be used in conjunction with agricultural R&D, the higher benefit-transformation curve BTC* would permit a greater quantity of both equity and efficiency, such as at point **d** (E**, V**) on IC_1. The optimal solution could involve none of the research being targeted to equity, depending on the efficacy of the non-research instruments.

[Figure A-1: *Agricultural research trade-offs*]

Figure 1: Trends in prices and yields of cereals, 1961-2012



Source: Yield data are from FAO (2013); price series are from USDA-NASS (2013a).

Notes: All data pertain to the United States. The following commodities were included in the cereals average: barley, corn, oats, rice, rye, sorghum and wheat. To estimate an average yield for cereals, we divided the sum of the quantity produced of each commodity by the coresponding sum of area harvested. To estimate a real price index for cereals, the respective annual series of commodity-specific nominal prices were first deflated by an index of prices received by farmers (base year 1961) developed by the authors using data from Gardner (2006) and USDA-NASS (2009, 2010, 2013b). An index of real cereal prices was then formed by using the commodity specific value shares in the total value of cereal production as weights to aggregate the respective real price indexes for each of the included commodities.

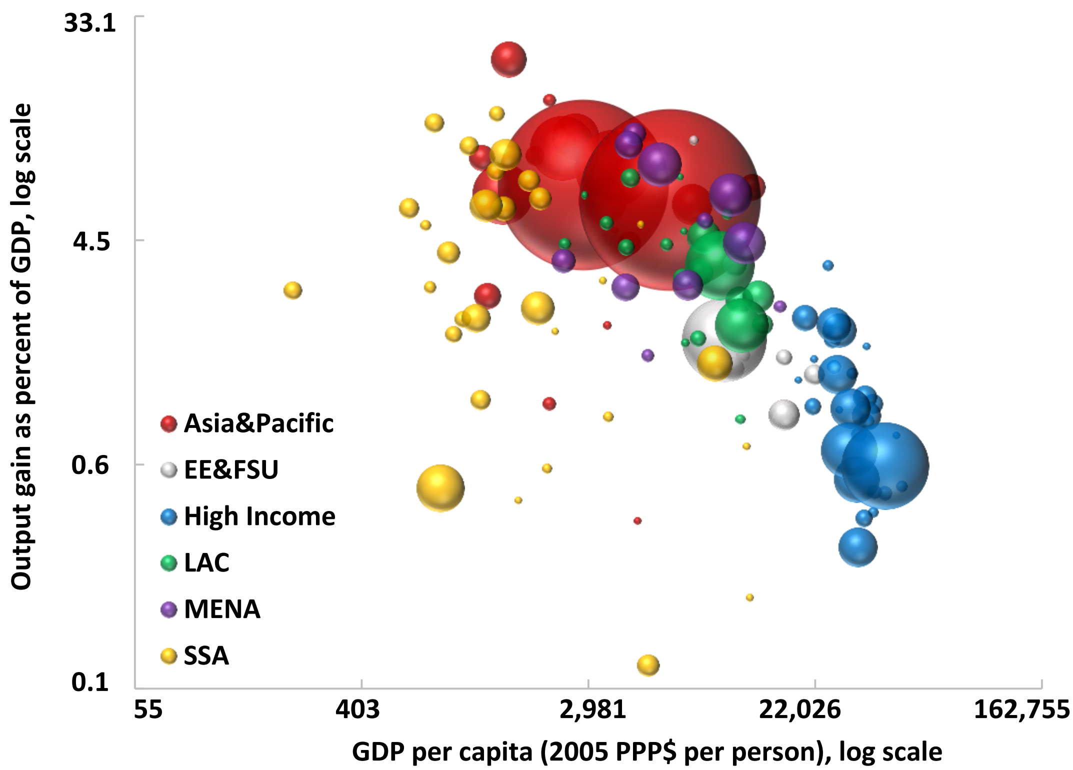
Table 1: The value in 2009 of agricultural TFP growth since 1961

	TFP in 2009 1961=100	AgGDP	Population	GDP per capita	Total Gain	Per capita benefits in 2009					Benefits as a share of GDP in 2009				
						All countries	Range excluding countries with negative TFP growth				All countries	Benefits as a share of GDP excluding countries with negative TFP growth			
							Mean	Median	Min	Max		Mean	Median	Min	Max
	index	*billion 2005 PPP$*	*million*	*2005 PPP$*	*billion 2005 PPP$*	*2005 PPP$*					*percent*				
By region															
Asia&Pacific	211	1,978	3,557	4,171	1,042	293	245	212	17	909	7.0	7.8	7.0	0.4	22.6
EE&FSU	148	251	406	11,239	82	201	307	225	152	825	1.8	2.9	1.6	0.9	11.0
High Income	246	472	1,018	33,355	280	275	292	262	9	883	0.8	1.0	0.9	0.0	3.6
LAC	211	317	582	9,301	167	286	285	266	103	575	3.1	4.0	4.2	0.9	7.9
MENA	233	305	390	7,593	174	447	381	445	81	700	5.9	5.5	4.6	1.6	11.6
SSA	124	335	843	1,899	64	76	72	44	4	244	4.0	4.5	3.0	0.1	13.9
World	198	**3,658**	**6,796**	**9,317**	**1,809**	**266**	**239**	**200**	**4**	**909**	**2.9**	**4.0**	**2.6**	**0.03**	**22.6**
By income group															
High income	235	510	1,082	32,442	293	271	288	264	9	883	0.8	1.0	0.9	0.0	3.6
Upper middle	228	1,648	2,575	7,913	924	359	339	315	23	909	4.5	3.6	3.1	0.2	11.0
Lower middle	175	1,266	2,369	2,982	541	228	189	183	5	527	7.7	5.9	5.2	0.1	15.7
Low income	127	234	770	1,017	50	65	78	36	4	332	6.4	6.6	5.6	0.5	22.6

Source: Authors estimations based on TFP data from Fuglie et al. (2012), AgGDP and GDP data from World Bank (2012) and population data from UN (2013a).

Note: All data and estimates pertain to year 2009. We estimated the country-specific gain from TFP growth using the TFP index from Fuglie et al. (2012) and added these country-specific gains by region and income group. We then derived the TFP index implied by these gains for each region and income group. “High income” in the first part of the table (under gains from TFP growth by region) excludes the high income countries that are part of EE&FSU, whereas “high income” in the second part includes all high-income countries as defined by the World Bank (2012).

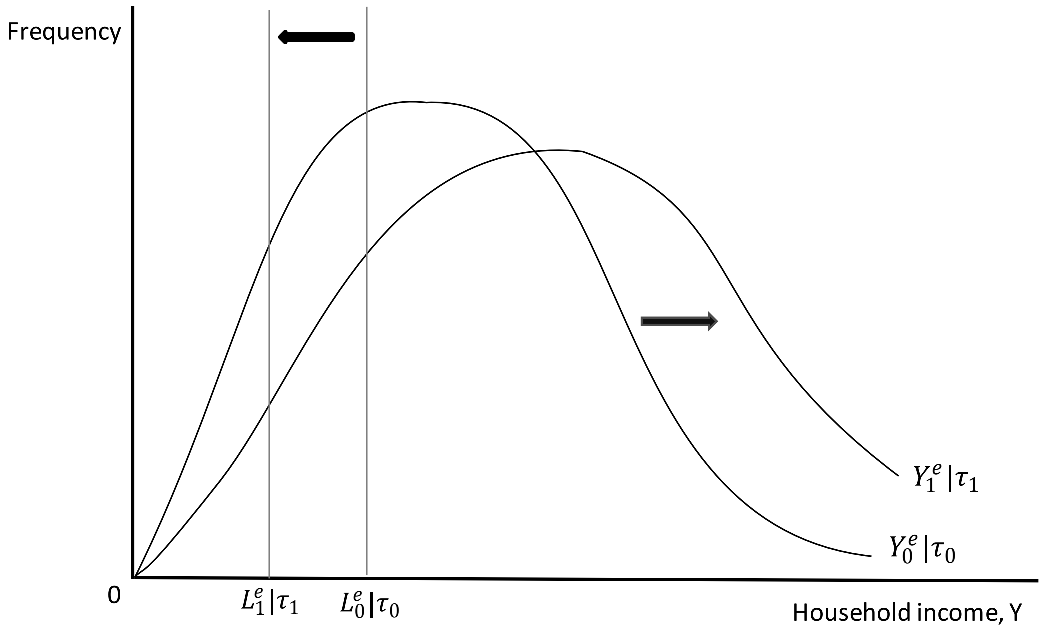
Figure 2: The comparative economic importance of agricultural productivity growth, 2009



Source: Authors estimations based on TFP data from Fuglie et al. (2012), GDP and agGDP data from World Bank (2012) and population data from UN (2013a).

Note: See table 1. According to estimates from Fuglie et al. (2012), 24 countries had declining growth in TFP from 1961 to 2009. Those countries were excluded from this figure. For expositional reasons, we also excluded Singapore, Puerto Rico, Kuwait and Qatar, countries where GDP per capita is comparatively large but output gain as a percent of GDP is exceptionally small.

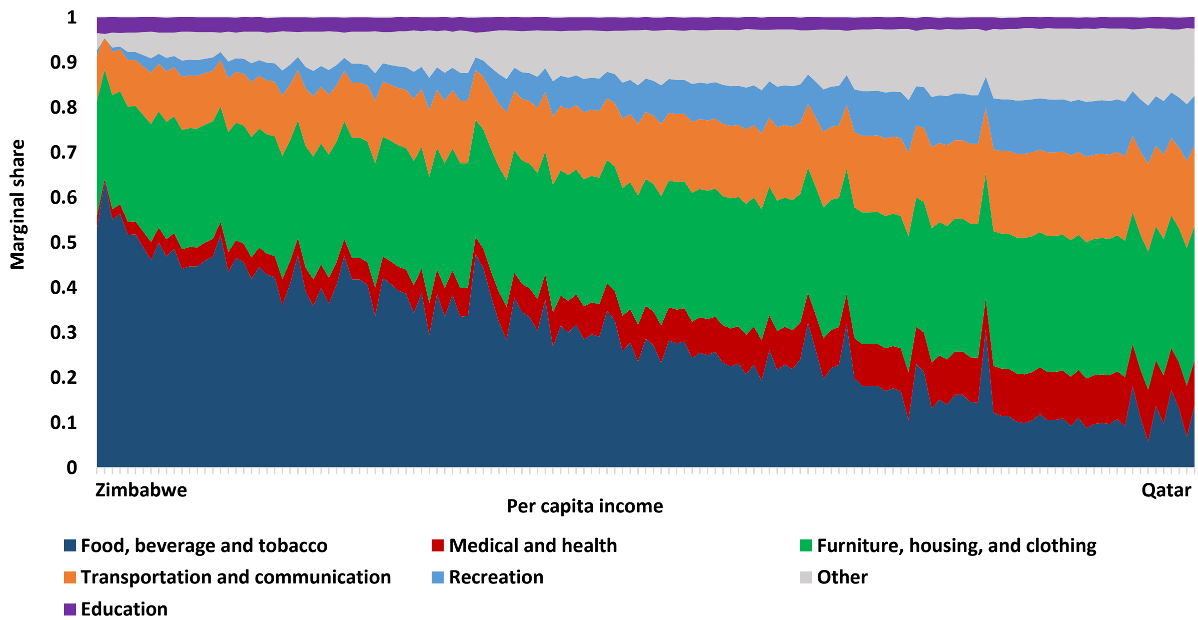
Figure 3: Agricultural technology and household income distributions



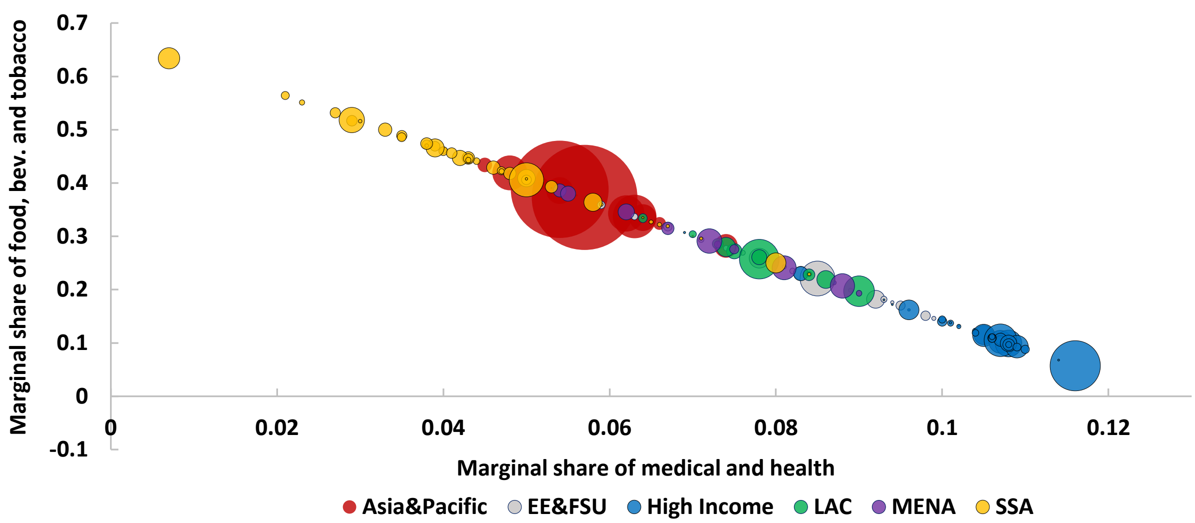
Source: Alston, Martin and Pardey (2014).

Figure 4: Country-specific average marginal expenditure shares by per capita income, 2005

Panel a: Marginal expenditure shares of per capita income



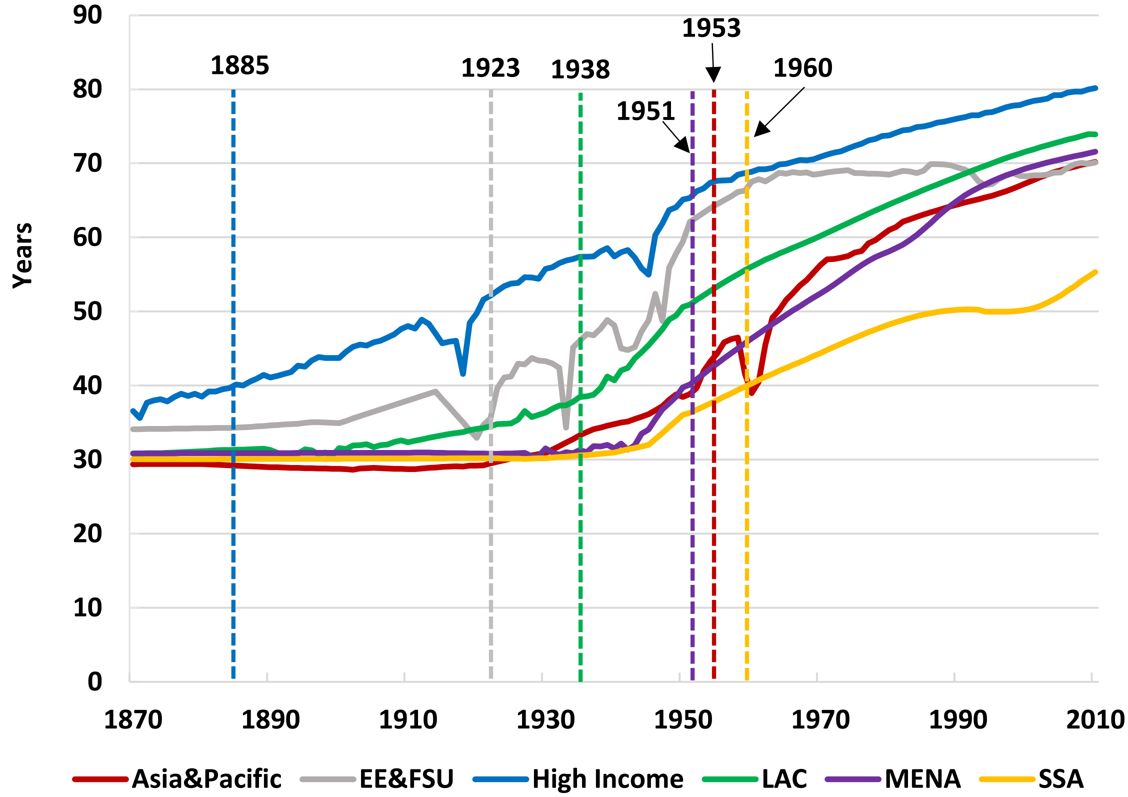
Panel b: Marginal expenditure shares of food beverages and tobacco versus medical and health purchases



Source: Marginal shares taken from Muhammad et al. (2011, Appendix Table 7); per capita incomes were computed by authors using GDP data from World Bank (2012) and population data from UN (2013a).

Note: The size of the circles in Panel b indicate the respective countries' shares of global population.

Figure 5: Average life expectancy at birth by world region, 1870-2010

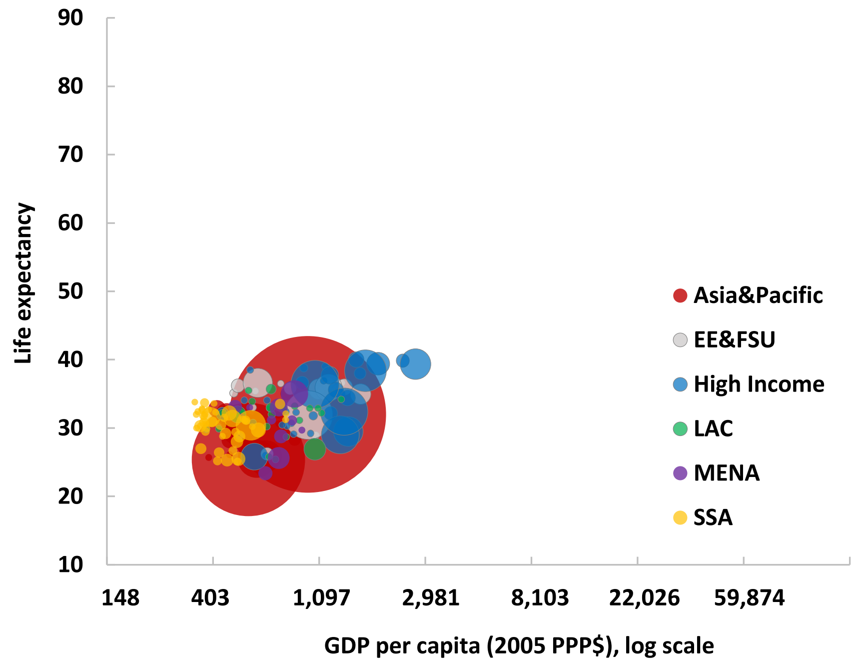


Source: Developed by the authors using data from Johansson and Lindgren (2013).

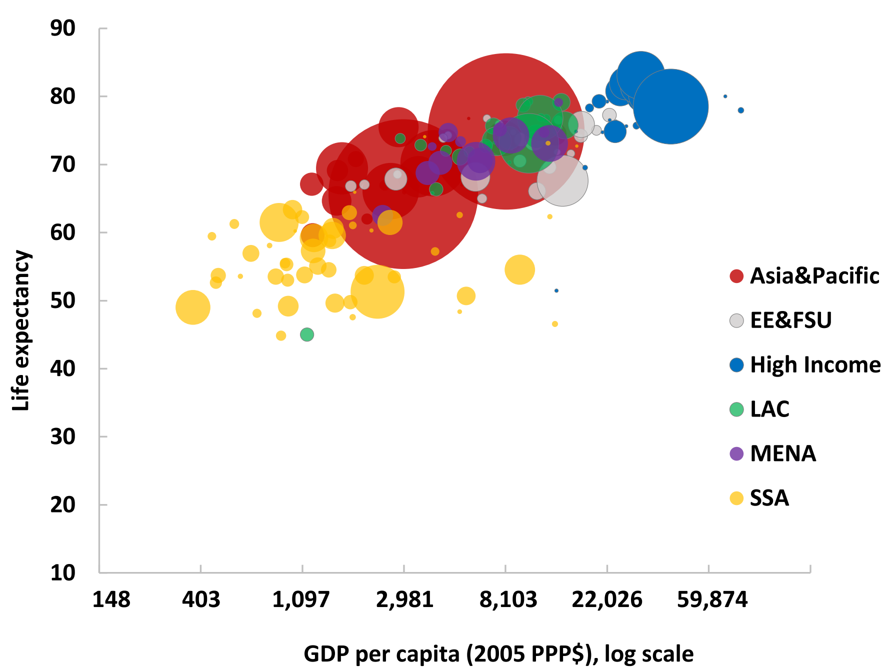
Note: The regional average life-expectancies plotted here were formed as weighted averages of the country-specific average life-expectancies, where the weights were the respective population shares of countries within their regions.

Figure 6: Per capita income and average life expectancy at birth, 1800 and 2010

Panel a: 1800



Panel b:2010

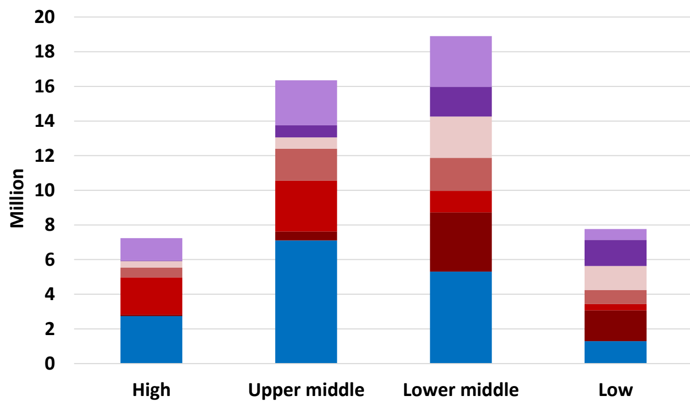


Source: Developed by the authors using data from Johansson and Lindgren (2013).

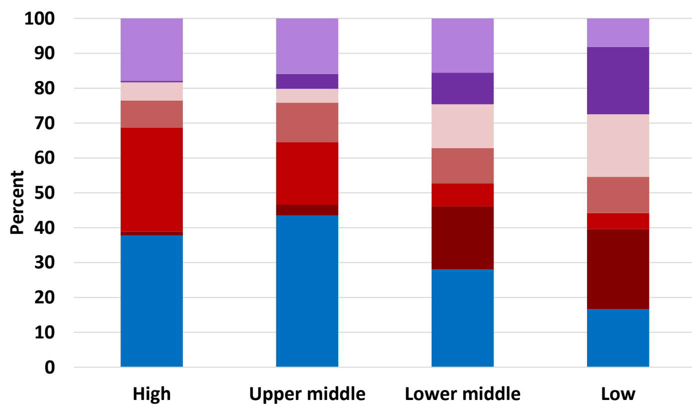
Note: The sizes of the circles indicate the respective countries' shares of global population.

Figure 7: Global deaths by category of disease and injury, and by income class of country, 2008

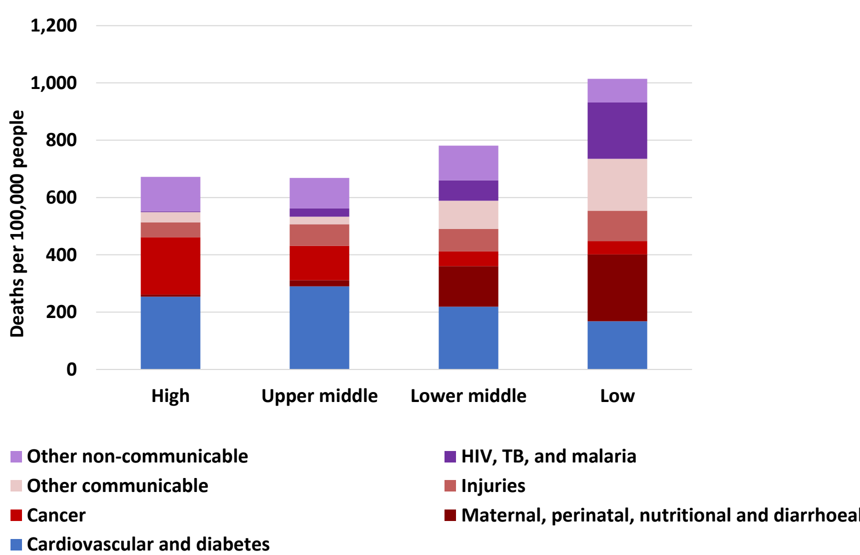
Panel a: Number of deaths



Panel b: Share of deaths

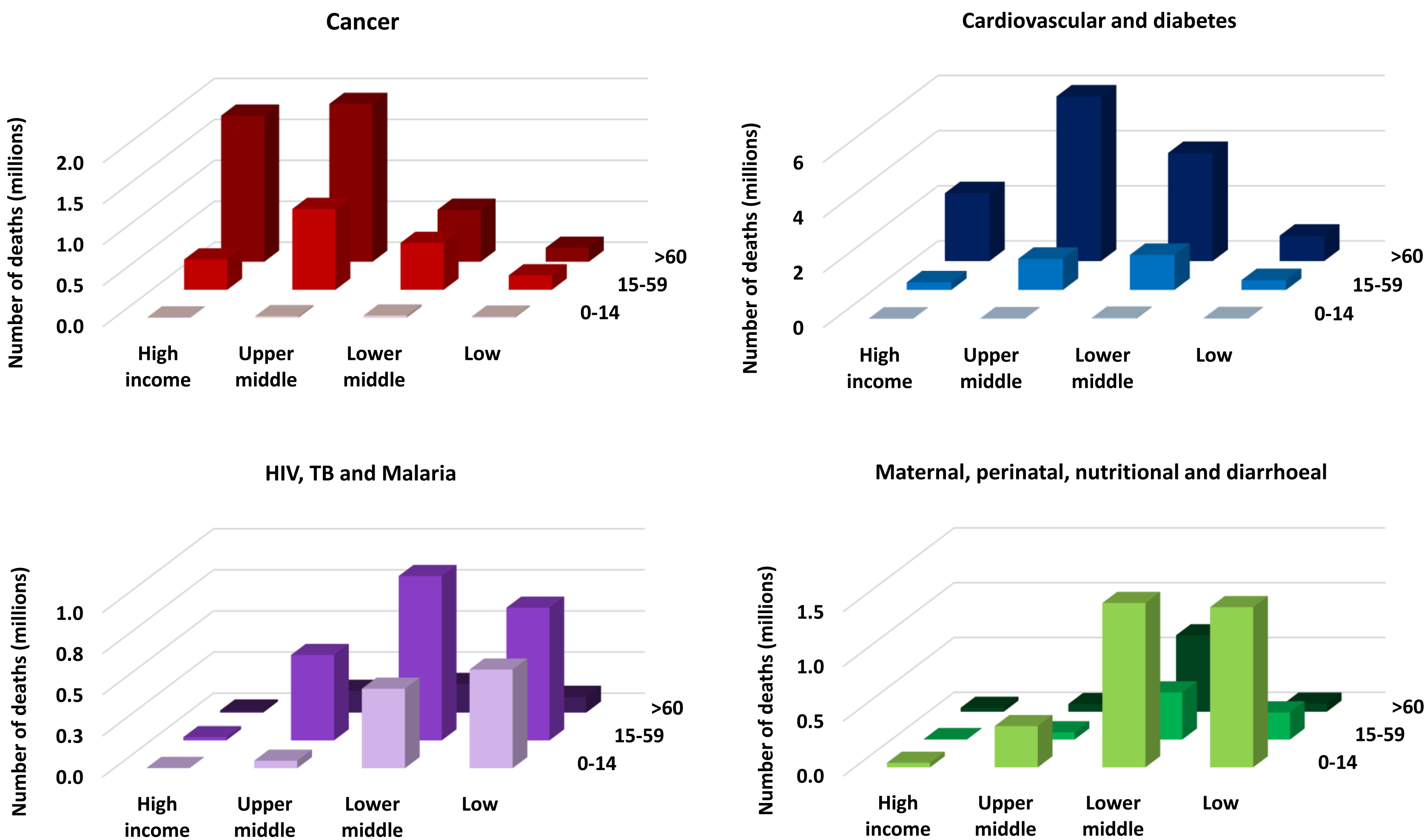


Panel c: Death rate



Source: Developed by the authors with data from WHO (2011) and UN (2013a).

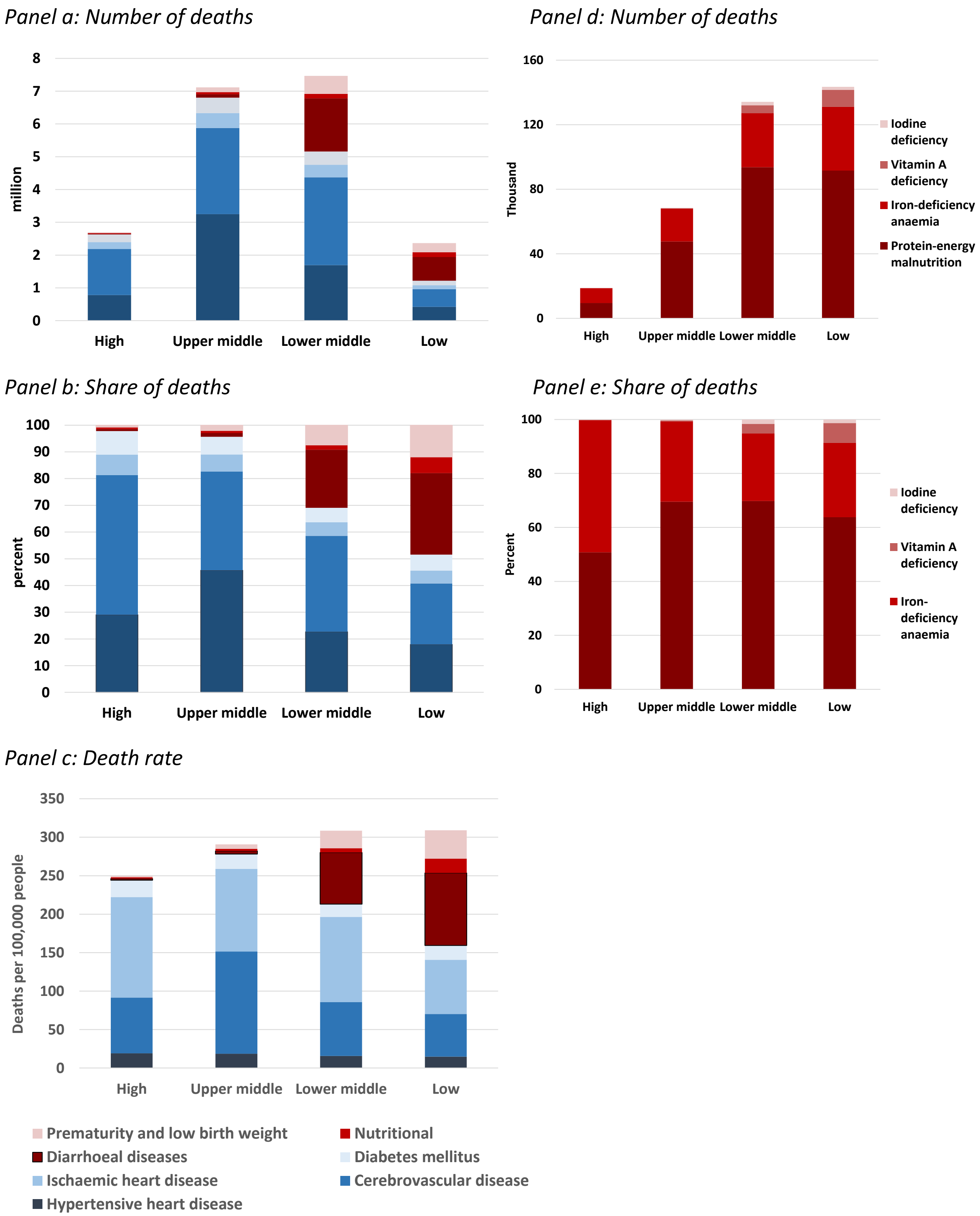
Figure 8: Number of deaths by category of disease, by age group, and by income class of country, 2008



Source: Developed by the authors with data from WHO (2011) and UN (2013b).

Note: Countries grouped into income categories according to data from World Bank (2012). Age cohorts in years.

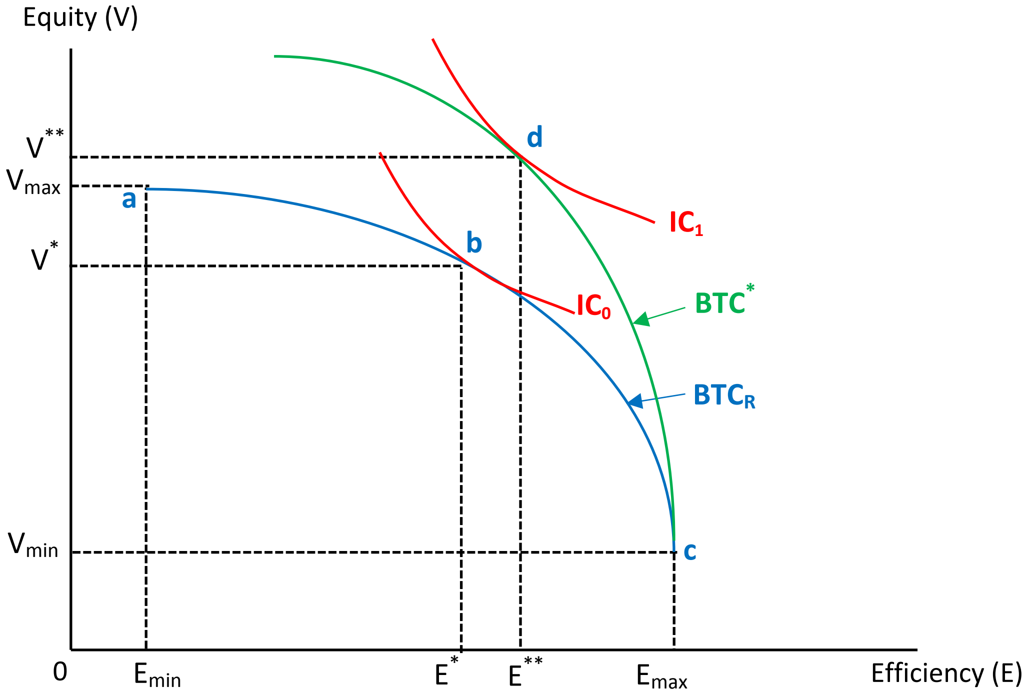
Figure 9: Deaths caused by nutrition related diseases, by income class of country, 2008



Source: Developed by authors with data from WHO (2011) and UN (2013a).

Note: Panels d and e provide finer details on the "Nutritional" causes of death identified in Panels a to c.

Figure A-1: Agricultural research trade-offs



Source: The authors, drawing on Alston, Norton and Pardey (1995, p. 90).